Fisheries Management and Ecology

Socio-ecological and economic aspects of tropical tuna fisheries in the Mozambique Channel

Journal:	*Fisheries Management and Ecology*
Manuscript ID	FME-20-178.R1
Manuscript Type:	Article
Keywords:	Purse seine tuna fisheries, Small-scale tuna fisheries, Fleet interactions, Shared stocks, Western Indian Ocean fisheries, Fisheries in Mozambique Channel

Response Letter

Prof. Ian Cowx Chief Editor
Fisheries Management and Ecology Journal

Please find enclosed the files with the revised version of our original manuscript ID FME-20-178 entitled "*Socio-ecological and economic aspects of tropical tuna fisheries in the Mozambique Channel*" by Nataniel et al. We would like to thank you and the reviewers for all the useful and very constructive comments, which we believe have improved our work significantly. We addressed all the reviewer's concerns, which were carefully considered or justified below. We hope the manuscript is now suitable for publication in Fisheries Management and Ecology journal. However, please do not hesitate in contacting us for further changes and improvements.

Best regards,

Anildo Naftal Nataniel on behalf of all authors

Reviewer #1

This manuscript studies the tropical tuna fisheries in Mozambique from socioecological and economic points of view. The main strength of this manuscript is to analyze both industrial and small scale fisheries and their possible interactions. I recommend acceptance of this MS in Fisheries management and Ecology after corresponding revision

We are deeply thankful for this comment. We worked on the manuscript revision following all the recommendations raised by the reviewers and the editor.

L444-446: For me it is difficult to imagine how the benefits of agreements could offset some of the current loss of FTE jobs (e.g., one or two weeks without fishing per month) among small-scale fishers due to adverse oceanic coastal environmental conditions for fishing.

Thank you for the comment. In the previous paragraph (lines 423 – 431) we explained the socioeconomic benefits for landing and transshipment of catches from industrial fleets, using examples from other developing countries. That is why we considered in lines 432-441 that if Mozambique implemented the decree (nº 74/2013), which proposes landing and transshipment in national ports, there would be extra part-time jobs that could partially make up for fishing days off, imposed by potential adverse oceanic conditions. However, James et al., (2018) suggested that the employment generated by landing and transshipment by the industrial fisheries may not benefit fishers directly, but, instead, they could benefit family members or other related people in the communities. As it is, we thought it would be safe to presume that "*the benefits of agreements <u>could partially offset the current loss of FTE jobs</u> (e.g., one or two weeks without fishing per month) among small-scale fishers due to adverse oceanic coastal environmental conditions for fishing, and improve statistical data*". We hope that this rewording has made the text clearer.

L 536-537 It has no sense to speak of tuna overexploitation only in Mozambican national waters since they are highly migratory species.
Thanks for this comment. The Reviewer is right; the stock is the same everywhere in the Indian Ocean. We removed this sentence in the revised manuscript.

Table 1: Please check FPA total contribution (€/year) since the two first columns ~~s~~eems to be in a different currency than the rest.

Thank you for noticing this. There was indeed a mistake here, which has been fixed. Please see the new Table 1 for an updated and corrected version.

Reviewer #2

This manuscript provides some useful information but needs to be thoroughly revised to remove ambiguity and contradiction. I have made comments below in relation to line numbers to emphasis these points.

We are thankful for the reviewer's comments. We carefully addressed their suggestions and criticism, as shown in the point-by-point responses below.

L7: Why does A declining trend in catches has been observed in the industrial fisheries sector, which has also been perceived by small-scale fishers, suggest that there is some competition between these two sectors for the same tuna stocks, even when these stocks are targeted in separate grounds. This needs to related to overlap of spatial of occurrence of a panmictic stock.

Thank you for this comment. The competition interaction mentioned here (line 6-9 of revised manuscript) is what Hampton (1991) classified as "The effect of fishing a stock in one area upon a fishery that exploits the stock elsewhere", i.e., different fleets or gears may target the same stock in different fishing grounds. This is particularly true for highly-migratory tropical tuna species in the Indian Ocean, which are part of the same stock (see www.IOTC.org for details).

L11: Ambiguity: Statements like "industrial fisheries sector may not be so economically advantageous" are ambiguous. They either are or are not advantageous – make a call on this situation based on data collected.

We revised this sentence to avoid ambiguity. The sentence now reads: " the industrial fisheries sector may only be more economically advantageous to Mozambique, if Fishing Partner Agreements are improved and enforced efficiently (line 10-11)".

L14: Why is this a major stress for the tuna?

We considered it a major stress because tuna stocks are continuously exploited both inshore and offshore by different fleets and gears. We reworded the sentence to make it clearer: "...it could also be a cause of major stress for the tuna, as they would be exploited relentlessly"(line 13 -14). This same issue is brought up again in lines 456 - 465 in the discussion section.

L30: what is the value of an ECU against any other currencies, e.g. dollar or Euro

The ECU was the monetary unit used by the European Monetary System before it was replaced by the euro in 1999. 1 ECU is equivalent to 1€. In this new version the conversion value is mentioned on line 28.

L58 – FAO stats stated in the 1986 so how does this rationalize with national stats stating in 2005.
Thank you for this comment. In lines 47 – 48 we mentioned the lack of official data for Mozambique. For example, Mozambique's national website (www.mimaip.gov.mz) and direct contacts made with the Mozambican fishing authority have shown that the tuna catch date only started to be recorded in 2005. However, other sources bring scattered and reconstructed information on the country's catches, including those provided by FAO (2004), IOTC (from 1980s on) reconstruction made by the Sea around us project (from 1950 to 2014), and IEO (from 1980s on), among other sources.

L84- 87: You state there are huge information gaps on the SSF yet on L70 you indicate there are 130,000 fishers (Chacate and Mutombe, 2018). How does this study reconcile with the previous assessment? There also seems to be a lot of information on the commercial fisheries L135-145.

Thank you so much for your comment. Information gaps are especially prominent in SSF, to which there are no continuous fishing statistics for Mozambique. For example, the 130,000 small-scale fishers mentioned here (lines 56-59) were recorded in 2012, when the 2007 census was updated. Prior to 2007 there was barely any information on SSFs. Since 2012, the fishing authority has been working to gather SSF data at national levels, but no updated statistics have been made available to the public. On the other hand, commercial fisheries have alternative sources of information (mostly international), as those presented here, i.e., commercial fisheries are usually better monitored because they're international and they usually sell their product to another party, for which tracking exists.

L88-91: Although an admirable objective, this was clearly highlighted by de Bruyn et al., in 2012 – so needs also to highlight what progress has been made since that time. This is particularly pertinent because thus study only collects data up to 2014.

Thank you for this comment. Maybe we confused the reader by the way we placed the citation of "de Bruyn et al. (2012)". However, de Bruyn et al. (2012) suggested how scientific precautionary approaches have to be taken in consideration for the management of tuna fisheries, but their study was neither done in Mozambique nor did it use a similar approach or methodology. To avoid the confusion, we removed the citation.

Section 2.2: the data on commercial fisheries were collected between 1983 and 2014, yet you state the national data were only collected since 2005. Also the SSF interviews were collected in 2017-2018 and there seems to be no indication of recall biases. This needs discussion.

Commercial fisheries refer to the industrial fleet data provided by IOTC and IEO sources because of data scarcity at the national level. Although the industrial purse seine data started being recorded at the national level from 2005 as mentioned in lines 47-48 of the introduction, we still chose to use the data provided by IOTC-commercial and IEO-Logbook data as they provided more refined data, in addition to the SSF interviews, made by us in 2017-2018. We have now explained it why we did not use the national data (Methods, lines 106 – 107).

L188 – is 101 interviews representative of the 130,000 SS fishers in the region = age is not the only variable indicating representativeness. It should cover fishing mode and area?

Thank you for these comments. The 130,000 SSF include all fishers targeting tropical tuna, non-tropical tuna and tuna-like species (line 56 – 59). But 101 interviewed fishers are those found in the field targeting the three tropical tuna species, which were the aim of this study. According to the information obtained in the field during the interviews, less than 10% of the SSF fishers have been targeting tropical tuna species due to the lack of fishing technologies and experience (line 151 of the methods). We included (lines 170 - 174) the number of fishers interviewed in each fishing region and details on their fishing gear, noting that artisanal fisheries usually use mixed gears.

L220 – determining FTEs is a useful approach but is the effort of a part-time worker per part data equivalent to fulltime worker operating over the same time period?

This is particularly relevant because you are unable to discriminate subsistence from commercial orientated SS fishers L218, FTE is a unit of measurement of the average number of workers doing a specific task, in a way that makes them comparable, although they may work a different number of hours per week or month. Please see lines 203 -210 in the Methods.

L245: What do you mean by “it concentrated most of the catches during the study period” - how and over what period were they concentrated? It seems the phraseology is odd and you probably mean “accounted for”.

Thank you for this comment. As suggested by the Reviewer, we replaced the expression “it concentrated ...” by “accounted for...”. Please see line 224.

L269: The statement “Most of the fishers interviewed reported that the largest tuna they had ever seen had been observed between 5 and 10 years prior to the reference years 2017 to 2018, when the interviews were conducted” contradicts the following statements that suggests this was caught between 1975 and 1980 for older fishers.

We meant that many fishers (77% out of 101 interviewed), who happened to be mostly younger fishers, reported that they have seen/caught their largest tuna between 5 and 10 years prior to 2017 to 2018. However, when fishers were divided into two groups (< 10 years’ experience vs > 10 years of experience) the more experienced group reported that their largest tuna happened to be seen or caught between 1975-1980. Please see the lines 251-256 of the revised manuscript, where we hope to have made it clearer now.

The two large fish a caught in 2008 and 2-17 presumably were not taken by the fishers interviewed, so this whole section needs rewording for accuracy. One must also question the declining trend in Figure 4 given the r2 is 0.12 and thus has no explanatory power – indeed the figure does not suggest any trend it is only the weakly fitted line that driver this interpretation.

Thank you for this comment. We now state that the two individuals weighing 100 kg each were “observed” in 2008 and 2017, respectively. Please see the revised line 258. In Figure 4, we estimated a rate of change which indicates a declining sign of about 2.5% between 1975 and 2017. But the reviewer is correct, the fit of the curve is indeed poor, which we have now acknowledged. Please see new lines 259 - 260.

L314: What about the numbers of gears this is the parameter – proportions hide the true scale of fishing pressure. Empirical data on fishing pressure between regions is needed here.
Thank you for this comment. The statistics of the 5 years prior to 2017 (Afonso et al., 2017) showed that Region A got about 10445 licenses, 2197 in region B and 2161in region C. However, these statistics refer to the official number of fishers registered as artisanal fishers, and not specifically those targeting tropical tuna. Lines 138 -154 in the methods describe how we collected the data from fishers given that not all fishers have been targeting tropical tuna in the area. Additionally, many artisanal fishers are not registered in Mozambique, and are not included in the official statistics. Furthermore, official statistics available do not usually include details of gears and boat types. It is important to note that artisanal fisheries usually use a mix of gears, from gillnets and handlines to small seiners, and that proportions seem to change from region to region (see lines 297 -302 and table 3 for details obtained through interviews).

L318: What is the reason for different crew sizes – is it linked to boat size of gears used.
The difference in crew sizes is related to the boat size, where the smaller the boat, the smaller the crew size (hand line: 2.5 – 7 m; gillnet: 4 -10 m, and small seine: 8 – 12 m) (please see lines 303 - 307 and Table 3).

L322: what do you mean by working loads? Do you mean crew size per boat? Also how many boats in~~I~~ each region – again this is to do with understanding fishing pressure.

We refer to working loads as the time the crew spend fishing per month. The fishing pressure is indicated indirectly by monthly FTE, which is about 14 and 15 times higher than a normal worker's FTE in regions A and B, respectively for gillnetters (please see line 302) and >30 times higher for small purse seiners (lines 314 – 315). It was hard to estimate the number of boats registered in each region due to the lack of statistics, in addition to the fact that very few people actually target tropical tuna.

L341: what do mean can reach 30.3% - it either does or does not!
About a third of the fishers interviewed in region C benefited from some sort of credit to invest in fishing. We clarified this sentence by rephrasing the paragraph. Please see lines 320 -322 of the revised manuscript.

L348: What about seine net fishers in region C – state no fishers found. Don't expect the reader to go to table. The same for gill nets. Also I discussion the reason for this is needed.

The reviewer is right, the text should have been clearer. We included a sentence in lines 295 – 296 mentioning that we did not met fishers in region C operating small purse seine and gillnet during the interviews. We also discussed this point in lines 473 -476.

L364-: Discussion – there is considerable repetition of information for the overly long introduction and the discussion. It would be better to simplify the introduction to the issues that are being explored and the discussion to provide the details and interpretation of what is happening.
We agree with the suggestion and we now bring a shorter and revised version of the introduction and discussion. We tried to remove all sorts of repetition or less relevant information.

L383: You indicate climate change may have an effect but how and how is it manifest in the catch rates?

We included an explanation on how climate change may affect tuna redistribution in the region in lines 370 – 378. Basically, we explain that "Alarming oceanic warming (Popova et al., 2016) may induce climate change with implications on the seasonal migration and aggregation of tropical tuna in the Mozambique Channel. For example, species are predicted to shift their aggregation toward southern and temperate waters by the end of the century (Dueri et al., 2014; Marsac, 2017) or displaced elsewhere and moving to deep water in the ocean (Monllor-Hurtado et al., 2017). These changes ultimately may have implications on fleet behaviour and the strategies they adopt..."

L189-:What evidence do you have to support the assertion that the two fishing sectors are exploiting a panmictic stock.

Both industrial and SSF fleets are exploiting the same stock of tuna. According to the IOTC, there is a single stock for each tropical tuna species in the Indian Ocean (see IOTC.org for details, here). This is usually true for large pelagic and highly migratory species, such as tropical tuna - skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*) and bigeye tuna (*Thunnus obesus*). Please see lines 381 -384

L399: shape is a coffee table expression – stock condition is the scientific term!
We corrected it as suggested by the reviewer. Please see line 391

L401-407. How can you say there is competition then say there is a lack of data to support it?

Our study shows, based on commercial and logbook data, that tropical tuna (bigeye tuna, skipjack tuna and yellowfin tuna - for which a single stock exists for the whole Indian Ocean per species) are being caught in Mozambique EEZ by industrial fleets and SSFs (e.g.: Mutombene et al., 2017; Chacate and Mutombene, 2019; Chassot et al., 2019). Meanwhile, results from interviews show that the same species are targeted by small-scale fisheries. According to some authors (see, for example, (Kleiber, 1991; Hampton, 1991) competition may happen when different fleets target the same species and stocks, even if their fishing happens in separate fishing grounds, which is the case here. Please see Figure 2, supplementary material (Figure S2, and Figure S3) about the tuna species for this study. The lack of data mentioned in lines 392 – 396 are those required to quantify the intensity of the migratory behaviour between coastal and high sea fishing ground.

L437 – Solomon Islands
Thank you, we corrected it accordingly.

L437-453: I find it difficult to compare small island state measures to large mainland country. The way fisheries are managed and exploited (including market chains) are very different and this needs discussing.
Thank you for this comment. We agree that there could be different management systems between islands and mainland countries. But in this paragraph, we are discussing the benefits of landing and transhipments of catches in national ports. We believe that the adoption of such measures would be beneficial for both small Islands and mainland countries, even though the effects may be more pronounced in the first. We have made that clear now in lines 424 -432.

L459: If the stocks are considered in good condition (note correct terminology) then how can the stocks in Mozambique be overfished. There seems to be contradictory interpretation here given these are straddling stocks.

Thanks for these comments. We corrected the terminology "good condition" by not overfished and not subject to overfishing (line 389 - 392). In lines 443 - 455 we discuss the potential negative impact of FPAs, which have been linked to overfishing in other African nations and elsewhere in the world (Nagel and Gray, 2012; Augustave, 2018). For the three tropical tuna the IOTC working parties on stock assessment determined that bigeye and skipjack were not overfished and not subject to overfishing, while yellowfin tuna was determined to be overfished, with overfishing still occurring (Lecomte et al., 2017; Augustave, 2018; Davies and Markides, 2019; IOTC, 2021)

L472-: But you have argued that the SSF and commercial fisheries operate in different areas so why is this a problem that needs intervention. The big issue here is the exploitation of the stocks not fishing area or seasonal discrimination.
In lines 451 -455 we discuss how different actions (e.g.: subsidies in fishing) could stimulate increased fishing pressure or competition among fleets and the implications of those on shared stock exploitation, even if the fleets operate in different fishing grounds.

L522 Conclusions. I can see little value in the conclusions section – it is repeating the facts for a third time. The final paragraph of the discussion is more than adequate for wrapping up the paper.
Thank you for this comment. We moved the last paragraph from the discussion to the conclusion section with some adjustment to avoid repetitions.

Editorial comments

Please note I suggest you drop the "Insight from Mozambique" from your title when you resubmit to widen the appeal of the paper.

Thank you for this comment. We dropped the stament “Insights from Mozambique” as suggested. Now the title is *“Socio-ecological and economic aspects of tropical tuna fisheries in the Mozambique Channel”.*

The paper is written in the active personal voice (we did...) instead of the passive voice as stated in the author guidelines. Please adjust throughout.
Thank you for this comment. We revised the entire manuscript writing to reflect the passive voice as recommended in the authors guidelines.

FME uses 31 December 19## as the date format not December 31st. Adjust throughout.

Thanks for mentioning this. We adjusted the dates in the manuscript as requested.

There is a considerable mixing of tenses in the manuscript from active voice (see above), but also past tense (was found) and passive tense (has been found). It is preferable to use past tense throughout ~~out~~ as this is factual.
We have revised the paper to use only simple past tense.

Do not capitalise the names of tuna – they are common names.
Thanks for pointing this out. It has been corrected everywhere in the manuscript as suggested.

Programme is spelt with ..mme unless it a computer program.
We corrected it as suggested. We used "program" in the first draft because the paper had been corrected for American English.

All units should be in tonnes or t not ton – ton is imperial unit
We have updated it to tonnes.

Do not use statements like In fact (line 55) - it has to be a fact.
We corrected it as suggested (see new line 45).

Line 65 - what does etc. mean here, specially as the list starts with e.g.
Thank you for pointing out the mistake. We revised the technical writing and deleted the “etc.” which was not appropriate. Please see new line 53.

Line 76 - Anecdotic + characterized by or given to telling anecdotes – this should be anecdotal - of or pertaining to anecdotes

Thank you for this comment. We replaced “anedcotic” by “anecdotal”. Please see line 62 of the revised manuscript.

Line 96 – give scientific author (with correct use of brackets around the name – check Fishbase for accuracy) on first use.
We now provide the scientific author for each species on first use as suggested. Please see lines 80 -81 of the revised manuscript.

Line 194 - subset is not a verb but a noun – rephrase
We rephrase it as "Macro-scale industrial purse seine data from the Mozambique EEZ were gathered from each database ....”. Please see new line 176.

Line 289 - kilograms is kg not Kg. adjust throughout.
We edited all kg in the new version of the manuscript.

Line 266 – do not use phrases such "Table 1 summarises the revenues…" here and elsewhere with reference to tables and figures. State the key point and cross reference to the table or figure. It is not for the reader to interpret the table or figure but the author. Adjust throughout
We have done as suggested.

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Socio-ecological and economic aspects of tropical tuna fisheries in the Mozambique Channel

Abstract

Industrial and small-scale tuna fisheries in Mozambique may compete over the same resources, which has potential socio-ecological impacts. The two types of fisheries were investigated by characterizing their catch trends, types of interactions, number of people they employ and revenues. Commercial landings, logbook data, and all previously established tuna Fishing Partner Agreements in the country were analysed as well as data collected from interviews with small-scale fishers. A declining trend in catches was observed in the industrial fisheries sector, which was also perceived by small-scale fishers, and suggests that there is some competition between these two sectors for the same tuna stocks even when these stocks are targeted in separate grounds. Whereas the small-scale tuna fisheries sector provides thousands of local direct and indirect jobs and high economic benefits for fishing communities the industrial fisheries sector may only be economically advantageous to Mozambique if Fishing Partner Agreements are improved and enforced. Although maintaining non-overlapping fishing grounds between industrial and small-scale fisheries may be positive for the fishers it could also be a cause of major stress for the tuna, as they would be exploited relentlessly.

Keywords: *Purse seine tuna fisheries, small-scale tuna fisheries, fleet interactions, shared stocks, Western Indian Ocean fisheries*

1. Introduction

The story of how tuna fishing began in Mozambique starts in the second half of the 1970s, when the Soviet Union started a research programme on large pelagic fish (Simões, 1984a) using a drifting longline to map the space use and seasonality of tuna schools. In 1983, chartered vessels from Cape Verde began experimental fishing with pole and lines and live bait (Simões, 1984b). With promising results, Mozambique issued commercial fishing licenses to vessels from France, Portugal, Spain and the Soviet Union between 1983 and 1984 (Simões, 1984b). This was the same path of other developing countries, who placed tuna exploitation in the hands of international fleets through environmentally and socioeconomically dubious fishing agreements (Havice and Reed, 2012).

The first fishing partner agreement (FPA) between the European Commission (EC) and Mozambique was signed in 1987 (EC, 1987). Authorized European vessels were subjected to pay the Mozambique authority fishing licence fees equivalent to 1,000.00 European Currency Units (ECU, i.e., 1 ECU is equivalent to1€) for the right to catch 50 tonnes of tuna in waters under the jurisdiction of Mozambique (EC, 1987). This agreement was terminated in 1993 by Mozambique who deemed that the agreement was disadvantageous toward the development of the local fishing sector (EC, 2003).

A second agreement with the EC was implemented in 2004 for a period of three years. Fishing license fees were set at €3,000.00 for tuna seiners and €1,500.00 for long liners corresponding to 120 tonnes and 60 tonnes of tuna respectively. An updated third agreement was established between 2007 and 2011 when licence fees were set at €4,200.00 equivalent to 120 tonnes for tuna seiners and €3,500.00 equivalent to 100 tonnes for longliners (EC, 2007).

A fourth agreement came into force in 2012 for another three years. This agreement included: 1) compensatory fees to develop the fishery sector (e.g., construction and expansion of infrastructure, training of fisheries staff, increased and improved fisheries monitoring and surveillance, and increased capacity for scientific observation and data collection), 2) details of who should pay for the scientific observers onboard (whose presence had been a requirement since the first agreement) and 3) an increase in licensing fees (purse seiners: €5,100.00 for 146 tonnes, longliners: €4,100.00 for 118 tonnes) (EC, 2012). This agreement was renewed in 2015 however licenses were mostly limited to longline vessels (>25) with less than 10 licenses issued to purse seiners (Chacate and Mutombe, 2018). HoweverMozambique has not issued licenses to purse seiners since 2018 as the country seeks to negotiate more profitable fees with international industrial tuna fisheries.

In spite of these agreements Mozambique only began recording total annual catches (www.mimaip.gov.mz) in 2005. Renewal of agreements did not necessarily mean that the terms were fully met. The requirements to provide jobs for Mozambicans, to land and perform transhipment catches in national ports (EC, 1987; EC, 2007; EC, 2012) and to have Mozambican scientific observers onboard to monitor and collect data (EC, 1987; EC, 2003) were never implemented. In Mozambique jobs are rarely documented and benefits are mostly limited to fishing license fees (Afonso et al., 2017) whereas in the other Western Indian Ocean (WIO) countries (e.g., the Seychelles, Mauritius, and the Maldives) EU purse seine fleets generate more than 4000 jobs, corresponding to estimated economic benefits of between €22 and €40 million in 2014 (POSEIDON et al., 2014).

In Mozambique, most of the tuna-related jobs are in the small-scale fisheries (SSFs) sector, which does not follow any sort of agreement. For example, in 2012, licenses issued for SSFs indicated about 130,000 fishers were directly involved in catching tuna (neritic and tropical tuna) and tuna-like species (Chacate and Mutombe, 2018). As is the case with industrial fisheries, tuna SSFs also suffer from a lack of statistical information and sampling programmes to record catch and effort data. The situation is even worse when it comes to information surrounding the socioeconomic aspects of SSFs, and existing knowledge is either merely anecdotal or only available in the grey literature.

This study describes the interactions between the industrial fisheries and SSFs sectors in Mozambique coastal waters. It is clear that SSFs target the same tuna stocks as industrial fisheries (as these are panmictic stocks) but due to the technological limitations the grounds of the first are closer to the coast (Ruttan et al., 2009) which by law are not accessible to industrial fisheries (Mozambique Fisheries Law nº 22/2013). It is not known if the <12 nautical mile limit is enforced. Given that tuna stocks are shared both types of fisheries are expected to feel the effects of stock declines in the event of overexploitation or other causes (e.g., natural fluctuations, climate change). The extent of job creation by each fishing sector is also unknown in Mozambique. To fill these information gaps data from industrial purse seine catches in Mozambique's Exclusive Economic Zone (EEZ) obtained from external databases were combined with career-history interviews with small-scale fishers. This information will contribute to improving the scientific knowledge surrounding tuna fishing in the region. Additional and better knowledge can contribute to supporting a revision of the FPAs and assessing the trade-offs between Mozambique and foreign industrial fleets by using a precautionary approach to solve some of the pitfalls in management of tuna fisheries in Mozambique.

2. Methodology

2.1 Study location

The Mozambican coast is located on the west side of the Mozambique Channel (Figure 1). In this area, both Industrial and small-scale fisheries target different species of tropical tuna in this region which include *Katsuwonus pelamis* (Linnaeus, 1758; skipjack tuna - SKJ) *Thunnus albacares* (Bonnaterre, 1788; yellowfin tuna - YFT) and *Thunnus obesus* (Lowe, 1839; bigeye tuna - BET). Foreign industrial distant-water fleets harvest tuna with the use of hand lines, longlines and purse seine gears. According to data provided by the Spanish Oceanographic Institute (IEO) and the Indian Ocean Tuna Commission (IOTC), the main tuna fishing grounds in Mozambican waters for purse seiners extend from the centre to the northern part of the country (latitude <20S) (Figure 1). Data retrieved from IEO correspond to the logbook records of Spanish purse seine fleets, whereas data gathered from IOTC include all data from purse seine fleets who have FPAs with Mozambique (e.g., EU, the Seychelles, Mauritius, the Mayotte Islands, among others) (see data collection section for further details).

To access the eventual socioeconomic impacts of both the industrial and small-scale fisheries sectors sharing the same stocks small-scale fishers were interviewed in four provinces. These were grouped into three regions: Cabo Delgado - Region A (northernmost villages from Palma, Mocimboa da Praia, and Ibo Island) Nampula – Region B (center-north villages in Memba, Nacala, and Mozambique Island) and Inhambane and Maputo provinces – Region C (southernmost villages in Inhassoro, Tofo Beach and Inhaca Island) (Figure 1). Fishing in these villages,is carried out with canoes or wooden and fibre sailboats that are rowed, propelled or equipped with a small outboard engine of 15-50 HP. The gear used is mainly hook-and-line (with sardines used as dead bait) gillnets, and small manually-operated purse seines. The fish caught by small-scale fishers are either traded locally or kept for self-consumption, thus supporting local food security and livelihoods.

The coastal zones in Mozambique are characterized by a tropical climate marked by a wet season, from November to April, and a dry season, from May to October (Hoguane, 2007). The tuna fishing, for both SSFs and industrial fisheries, is very seasonal and typically begins in late February (wet season) and ends around the beginning of July (dry season) (Campling, 2012, Obura et al., 2018; Chassot et al., 2019).

2.2. **Data Collection**

2.2.1 ***Macro-scale data from purse seine tuna fishing***

Total landing commercial data were retrieved from the Indian Ocean Tuna Commission (IOTC) (www.iotc.org) the tuna regional fisheries management organization for the Indian Ocean convention area. We did not use the national data collected from 2005 on, as this was lacking in detail (total annual catches only). The IOTC catch data were stored by month over the period 1983 and 2014 at a 1º x 1º spatial resolution in a database for the FAO fishing zone 51. In addition to catches per species, the data file also included information on fleet, fishing grounds, date (year and month) fishing hours and, in the case of purse seiners, set type (i.e., whether fishing was conducted on Free Swimming Schools - FSC or on Fish Aggregating Devices - FAD (any type of floating object used to aggregate tuna). Furthermore, daily sets from logbook data for Spanish purse seiners covering the same spatial and temporal resolution were provided by the Instituto Español de Oceanografía (IEO) and were used to compare and complement tuna catch trends. The logbook data were more representative than the IOTC data because they were collected through a scientific sampling observation programme carried out by the IEO. Logbook data also included information on catches by species and fishing mode (FSC and FAD), fishing hours, date (year, month, and day of the fishing operation) and location of the fishing activity (i.e., longitude and latitude) and the fishing sets were aggregated as the sum of ¼º resolution. To estimate the Catch Per Unit Effort (CPUE) total catch per year was divided by total fishing hours.

To describe the socio-economic issues facing tuna fisheries over the last three decades on a macro-scale, publications from the Mozambique Ministry of Fisheries Authority database (www.mimaip.gov.mz) were revised and available data were retrieved from the European Union database (www.eu.org) to access the

Fisheries Partnership Agreements (FPAs) between Mozambique and the EU. Both peer-reviewed (Chassot et al., 2019) and grey literature, including technical and project reports about the socio-economic aspects of fisheries in Mozambique were also reviewed (Gorez, 2003; EC, 2007; Kusi, 2008; EC, 2012; POSEIDON et al., 2014; Afonso et al., 2017; Lecomte et al., 2017a; Lecomte et al., 2017b; Mutombene et al., 2017; Chacate and Mutombe, 2018) together with dissertations (e.g., Otterlei, 2011; MANACH, 2014; Mendiate, 2016; Augustave, 2018). Revenue data were extracted from the FPAs, but information regarding job creation for Mozambicans within industrial tuna fisheries segments was very limited.

2.2.2 ***Interviews with small-scale fishers***

Interviews with small-scale fishers were carried out between 2017 and 2018 in 10 villages in three different regions along the Mozambique coast (Figure 1). Additionally, the provincial and local fishing authorities in each village were contacted both during the scoping phase and throughout the course of the research to discuss the data gathered from fishers. Scoping revealed that small-scale fishers mostly target tuna in the northern and southern parts of the Mozambique coast, but rarely in the central region. Therefore, the study design included seven villages in the north (10ºS - 15ºS) three villages in the south (21ºS - 26ºS), and no sampling in the centre region, between 15ºS and 21ºS (Figure 1).

A semi-structured face-to-face questionnaire was utilized (Johannes et al., 2000; Wengraf, 2001; Babbie, 2012). The questionnaire had four parts (Appendix S1): personal information (e.g., age, experience, and education), tropical tuna catches (e.g., size composition of catches, seasonality, gear types, fishing equipment and techniques), socioeconomic aspects of tuna fishing (e.g., revenue, employments, value chain, fishing cost), and interactions between SSFs and industrial purse fisheries (e.g., types of interactions, use of FADs, potential impacts). The interviewee selection process relied on a combination of expert-opinion, key informant interviews, and snowball sampling as per recommendations from previous authors (e.g., Huntington, 2000; McGoodwin, 2001). Expert opinion surveys are a data collection technique in which the community council selects the most knowledgeable or experienced people in the village from a pool of potential participants to be interviewed (Huntington, 2000). Here, the community helped identify key participants, who were those that had more specific and detailed information on the catch of tropical tuna. Each interviewee suggested the names of other local experts, which corresponds to the "snowball sampling" technique (Huntington, 2000; McGoodwin, 2001). Snowball sampling method was especially efficient given that less than 10% of the fishers in each study village target tropical tuna. Furthermore, fishing authorities, village leaders, and key participants were initially consulted to recommend expert tuna fishers who might be available to be interviewed, given the lack of official fisher databases in both the villages and at higher levels.

The interviews were either conducted at fish landing sites or at fishers' homes. Prior to beginning the survey, fishers were told about both the goals of the research and what was expected of them. Only fishers with a minimum of 5 years of experience targeting tuna were considered. Interviewees were also informed that they had an option to participate or not, to leave the interview at any moment, or not to respond to specific questions. The interview proceeded after oral consent was obtained from the interviewee. Local fishing leaders were approached first in each of the study fishing villages to authorize the survey and to help identify potential experienced tuna fishers. Prior to applying the questionnaire, fishers were asked to freely talk about "good and bad" days of tuna fishing, both from the present and past. Only after this moment were fishers shown printed colour pictures and leaflets of the three tropical tuna species to make sure they were correctly identifying the species and the ones they have targeted. The interviews proceeded after it was confirmed that the fisher being interviewed had caught at least one of the three species shown. A technician representing the fishing authority and leaders of the community fishing council helped ensure the trust and collaboration of fishers for the interviews, which lasted, on average, 25 to 35 minutes.

A total of 101 fishers were interviewed, aged between 19 and 73 years old (41 ± 12, >32% between 41 and 50 years old), and who had been fishing for 5 to 55 years (21± 12, 80% ≥ 10 years of experience) (Appendix S2, Figure 1). The sample was balanced, with 33 fishers from region A (9 gillnetters, 14 hand liners and 10 small seiners), 35 from region B (5 gillnetters, 10 hand liners and 20 small seiners) and 33 fishers from region C, who all fished with handline. The literacy level of the interviewees was low, with 91.4% either illiterate or with less than four years of schooling. Contrary to industrial fishers, small-scale fishers rarely focus on a single species or even group of species, such as tunas.

2.3 Data analysis

Macro-scale industrial purse seine data from the Mozambique EEZ were gathered from each database using the QGIS 3.4 software (QGIS Development Team, 2018), aggregated to a ¼º x ¼º spatial resolution, and exported as a *csv* file for posterior statistical analyses in the R statistical software (R Core Team, 2018). The packages 'ggplot2' (Wickham, 2009) 'mgcv' (Wood, 2006) and 'polynorm' (Venables et al., 2016) were used to view and model fleet behaviour, tuna catch trends and CPUE. Three-degree polynomial order regressions were used, as they provided the best statistical score of goodness-of-fit (r^2) for catch trends for both logbook and commercial data. The number of people employed in fisheries and total revenues were the main social and economic indicators, respectively, for descriptive approaches of industrial fisheries.

With respect to SSFs data, it was investigated whether the largest tuna (kg) ever caught or seen (i.e., caught by another fisher) by fishers had changed over time, according to their own recollections of the size and year when the catch occurred (Tesfamichael et al., 2014). 'Largest individual tuna' was chosen as the ecological indicator to be recalled by fishers because tropical tuna species are often mixed with other species, including both pelagic species and neritic tunas, thus hampering fishers' abilities to understand best catches for only tropical tuna species. Referring to fisher memories is a relatively reliable strategy to estimate changes in catches (amounts and fish size) when official statistics are not available (Damasio et al., 2015). Again, polynomial regressions were used to analyse catch trends, specifically the relationship between the largest tuna ever caught and the year of occurrence.

Villages were also aggregated into regions in order to assess the environmental and local perceptions of fishers toward the social and economic impacts of tuna fishing in their villages. Fishers from nearby villages were assumed to share similar marine environments and, therefore, similar adaptation strategies, specific behaviour, fishing cultures and self-organization arrangements rooted in the exploitation of that particular environment (McGoodwin, 2001). F-tests were applied to compare the variability of reported means for species frequently caught by fishers per month among regions. Similar to the SSFs sectors in other regions throughout the world (McGoodwin, 2001), it is not easy to distinguish subsistence from commercially oriented fishing in the study villages. Thus, interviewees were clustered by gear types to allow comparisons among gear types within and among regions. Like the macro-scale descriptive analyses, the number of people employed and revenues were the main social and economic indicators considered. The monthly volume of work was converted into full-time equivalent jobs or employment (FTE). FTE is a unit of measurement of the average number of workers doing a specific task, in a way that makes them comparable, although they may work a different number of hours per week (ilostat.ilo.org). The unit was obtained by comparing the average working hours of the average crew using a specific type of gear (i.e., gillnet, handline or purse seine) to the average number of hours of a full-time worker in Mozambique (i.e., 1.0 FTE for a worker is equivalent to 8 hours/day x 5days/week x 4 weeks ≈160 hours per month). For this study, one Mozambican full-time worker was compared to the average crew, rather than the individual, given that the result of the crew's work is collective, rather than individual, i.e., total fish landed.

Because of the heterogeneity and lack of archive information relative to investments and the operational costs of fishing within and among gear types, individual revenue was assumed to be the best economic indicator for small-scale fishers. After the fish caught on a trip are sold, the revenue is divided among the crew according to one of three arrangements: (i) *self-fisher* - there is only one fisher, who also owns the boat and thus pays the costs and keeps the entire revenue; (ii) *team fishers* - first the daily operational cost (e.g., fuel and oil) are subtracted from total revenues, when applicable, then 50% of the remaining revenues go to the fisher who owns the vessel, and the remaining 50% is shared equally among the crew (excluding the boat owner); and (iii) *patron* - the boat is owned by a patron, who keeps 40% of the revenue (after discounting the operational costs); the remaining 60% of the income goes to the actual fisher(s).

3. Results

3.1. *Macro-scale purse seine tuna fisheries*

Industrial purse seine fisheries have been targeting tuna in Mozambican waters since 1983 (Figure 2a). Prior to this period, catches were seldom reported, even though Russians had been researching and fishing the Mozambican coast since the mid-1970s. Spain accounted for most of the catches during the study period (49% of the total accumulated catches over 30 years) (Figure 2). Between 1983 and 2014, Spain and France reported total accumulated catches of 58.1 and 37.2 thousand tonnes of tuna, respectively, while the regional fleets (e.g., Seychelles, Mauritius, Mayotte) together accounted for about 10.9 thousand tonnes, and overall, the NEIPS fleets (Netherlands, Italy, Greece, Portugal, Japan, Korea, and others), accounted for almost 12.2 thousand tonnes (Figure 2b). Regardless of the fleet, the main target has been skipjack tuna (Figure 2b), which accounts for more than 65% of the total catch during the study period (YFT and BET at 29% and 5% of catches, respectively).

The tuna catch trend is characterized by a semi-parabolic curve, regardless of the source of data (detailed Spanish logbook or general commercial data) (Figure 3). The Spanish purse seine logbook data shows catches increasing at a rate of 4.1% per year between 1983 and 2000, followed by a fast decline of 7.2% per year until 2014 (historical minimum). The overall purse seine commercial data shows a less pronounced annual increase and decrease, with an earlier decline than the logbook data. In the latter data, catches are shown to have first increased at a rate of 1.7% per year between 1983 and 1997, and then to have decreased at a rate of about 1.4% until the end of the time series (also the historical minimum). Therefore, there is some evidence to suggest that catches have been generally declining over the last 15 to 20 years; however, there is a high degree of variability within each dataset, i.e., the logbook (r^2=0.51) and the commercial (r^2=0.45) data (Figure 3a-b). The CPUE showed growth rates of 13.3% and 6.4% for logbook (r^2 = 0.42) and commercial (r^2 = 0.14) data, respectively, between 1983 and 1998 (Figure 3 c-d), followed by some stability, and another increase in the last three years of the time series (Figure 3 c-d).

The revenues from the EU fees to develop the Mozambican fisheries sector improved with every consecutive FPA (Table 1). For example, the FPAs approved in 2007 and 2012 contributed with €826,400 and €1,087,100, respectively (Table 1), which corresponded to ~ \$680,000 in 2007 and ~\$800,000 in 2012 PPP dollar value (PPP - purchasing power parity USD). The last fishing agreement expired in 2015 and has not been renewed.

3.2. Knowledge of small-scale tuna fishers

The largest tuna size recalled (in kilograms) by fishers demonstrated a declining rate of about 2.5% per year (Figure 4). Most of the fishers interviewed reported that the largest tuna they had ever seen had been observed between 5 and 10 years prior to 2017/2018. When fisher responses were separated into two groups, those with up to 10 years of experience and those with more than 10 years of experience, the younger and less experienced fishers reported that the largest tuna they had ever caught or seen (average = 40 kg) was caught around 2008, whereas the older and more experienced fishers reported that the largest tuna they had ever caught or seen (60 to 75 kg) was caught between 1975 and 1980. The declining rate seems to be more pronounced between 1975 and 1995 (3.2% annually), followed by a flattening trend. Despite that, the largest tunas mentioned by fishers were two individuals weighing 100 kg each that was observed in 2008 and 2017. Yet, the dispersion of the fisher's responses especially in the more recent years shows a poor adjustment of the data (Figure 4; $r2 = 0.12$).

The seasonality of tuna species occurrence also varied according to the region, according to fishers. They reported a higher occurrence of tropical tuna from late December to May in areas A and B (northern region), whereas in area C (southern region) species were reported to be mostly caught between late June and November (Appendix S2, Figure 2). The seasonality of fishing seems to be especially marked for skipjack, which is rarely caught between June and November in region A, becomes slightly more reported during this same period in region B, and then is said to be predominantly caught in this season in Region C (Appendix S2, Figure 2). Both bigeye and yellowfin tuna are also absent between June and November in Region A, but present at similar rates, or even higher, in Regions B and C in this season.

When fishers were asked about the average size (kg) of the tuna they normally catch, both bigeye (most catches between 5 kg to 30 kg) and skipjack tunas (between 1 and 7 kg) showed a positively skewed distribution, whereas yellowfin tuna (between 5 kg to 30 kg) followed a normal distribution (Appendix S2, Figure S3). Fishers reported that they mostly target skipjack, which, according to 83% of the fishers interviewed, is the main species occurring in the area (Table 2). The occurrence of bigeye and yellowfin tuna usually caught as juveniles, were reported by 53% and 60% of the fishers, respectively (Table 2).

The average size reported for skipjack in region A was larger than the average size reported in the other regions (A x B: F=4.01, p-values= 0.0003; A x C: F= 2.84, p-value=0.0133) (Table 2). No difference was detected between regions B and C (F = 0.7077; p-value = 0.3527). For bigeye and yellowfin tuna the average size did not vary across regions: bigeye (A x B: F=1.45, p-values=0.2932; A x C: F= 0.80, p-value=0.7757; B x C: F=0.45, p-value=0.1117), and yellowfin (A x B: F=1.95, p-values=0.2174; A x C: F= 0.77, p-value=0.5993; B x C: F=0.40, p-value=0.07305).

Over the last 5 to 10 years prior to 2017-2018, 65% (*n=101*) of the fishers interviewed perceived a decline in tuna occurrence. This was especially marked in region C, where 88% of the fishers interviewed claimed to have noticed this decline, in contrast with 50% of the fishers in the other two regions (Table 2). Despite the reported declines, most interviewees in region A (64%) still considered it easy to catch tuna, according to their fishing experience, gear used, and season. By contrast, in regions B and C, almost 63% of the fishers suggested that it was difficult to catch tuna due to either a lack of technologies or scarcity of tuna (Table 2). The vast majority of fishers (~85%) claimed that tunas are mostly caught at sunrise and sunset (Table 2).

In general, fishers did not perceive much overlap in fishing grounds between industrial purse seiners and their own activity, although the situation is less clear in Region C (A= 76%, B = 94%, C = 58%), which suggests that there are some eventual overlapping grounds (Table 2). The interviewed fishers have never seen FADs lost from industrial seiners, nor do they use FADs to attract fish (Table 2).

3.3 **Socioeconomic aspects of small-scale tuna fisheries**

The three regions differed in the proportion of gear types used (Table 3). In region A, hand lines predominate (45.5% vs 30.3% small seine vs 24.2% gillnets), whereas in Region B small seines are used by the majority of fishers (57% vs 29% hand line vs 14% gillnets), and in Region C, in the south, only hand lines are used in visited villages in region C.

The distribution of fishing gear and how they are used across regions also affects the number of people employed in each place. For example, the crew sizes of boats that operate gillnets in Region A range from 4 to 20 fishers per vessel, compared to 6 to 17 people per vessel in Region B, where the smaller the boat, the smaller the crew size. The average daily working time for gillnet fishers is ~11 hours in both regions A and B, and approximately 17 to 19 average days per month. Therefore, the monthly average working loads were estimated at 14.2 ±0.3 and 15.1 ±0.2 FTE jobs for areas A and B, respectively (Table 3).

With respect to handline fishers, the average crew size is 3 ± 2 and 5 ± 2, and ranges from 1-7 in regions A and C, while in the villages visited in region B, fishers worked alone. The average working time for handline fishers was around 10 hours per day for all three of the visited areas. Handline fishers declared an average of 21 fishing days per month in areas A and B, while in region C the declared average was about 15±4 days per month. Hence, the monthly workloads for handline fishers were set to 3.89 ± 0.7, 1.3 ± 0.3, and 5.1 ± 4.99 FTE jobs in the villages in areas A, B, and C, respectively (Table 3). Compared to the normal working hours of the average worker in the country, the monthly working hours are relatively higher in areas A and C, being close to the average workload in area B, because in area B fishers mostly work alone.

On average, small seines provide more jobs than the other gear (26 ± 6 and 23 ± 9 fishers in region A and B, respectively). The working load for seiners is about 12 hours per day in villages in region A, and 11 hours in villages in region B, with working days set to an average of 18±3 and 20 ±3 in region A and B, respectively. Hence, compared to a full-time employee, the monthly workload was found to be 34.4 ±12.3 FTE jobs in region A, and 32.9 ±22.1 FTE in region B (Table 3). This is the highest workload among all previously described fisher groups, and >30 FTE times higher than the average monthly hours of an average worker.

In all the fishing villages evaluated, most fishers (>50%) have to invest time and money to maintain their fishing equipment, while less than 23% of fishers interviewed, i.e., those working for a patron, do not know who funds their fishing. Few fishers have been beneficiaries of any type of credit (e.g.: government subsidies, loans from NGO or banks), although in region C 30.3% of the fishers had access to some sort of credit (Table 3).

Gillnet fishers are remunerated based on a shared income team-fisher system (type *ii*) (Table 3). Overall, gillnet fishers in region A make 1,5 times more money than fishers in region B. Boat owners were only accessed in region B, and were found to make more than twice the amount that fishers make in the high season (December - May), and 82% of the average fisher income in the low season (June - November) (Table 3).

Small purse seiners are also arranged in a team-fishers' system (type *ii*) and share fishing revenues (Table 3). In region A, boat owners earn, on average, about 1.5 times more than the fishers working for them. In region B a boat owner makes more than 2 times more than fishers make in the high season and 89% of what fishers make in the low season. When regions are compared, boat owners from area A make 84% of the average income of boat owners in area B in the high season, and similar incomes in low season. The incomes of fishers, by contrast, were similar between regions A and B in the high season. In the low season, fishers from region A earn an average of 76% of what fishers in region B earn (Table 3).

Hand line fishers who are boat owners and patrons were only assessed in region C and were found to make about three times more money in the high season than in the low season. Regardless of the season, patrons make almost twice the amount earned by fishers who are boat-owners. In region A, independent fishers make

29% of the average crew fisher's income in the low season, and 46% in the high season, respectively (Table 3). Independent fishers in region A were found to make more than twice that of independent fishers in region B in the high season, and three times as much in the low season, respectively. Crew-member fishers in region C were found to make about 60% of the average fisher's income in region A (Table 3).

4. Discussion

Although the record of fisheries statistics in Mozambique have been improving in the last two decades (Afonso et al., 2017) the country still struggles to offer high-resolution temporal and spatial information by species caught in the Mozambique EEZ. This is why an assessment of industrial tuna fisheries in Mozambique requires the use of international data, as done here, together with interviews with small-scale fishers. Hence, the implementation of the provisions included in the FPAs, where fisheries statistics, regional offices, observers, etc. are requested to complement the inconsistence or scarcity of data. However, relying on fishers' knowledge is a relatively reliable strategies to gather information data and estimate changes on fisheries when official statistics are inconsistent or not well documented (Huntington, 2000; Damasio et al., 2015).

Foreign purse seine tuna fleets, especially European fleets, have been fishing in Mozambican waters since the 1980s. Between that time and the 2000s, industrial purse seine tuna catches increased at a rapid rate, as indicated by a growing number of licences issued to European purse seine vessels, mainly from France and Spain (EC, 1987; Parks, 1991). These vessels were equipped with advanced fishing technologies (Fonteneau et al., 2013; Lopez et al., 2014; Lopez and Scott, 2014; Torres-Irineo et al., 2014) that enabled an increased fishing effort. After the 2000s catches started to decline, in part because a number of fleets exited the fisheries industry in response to high levels of piracy observed in the WIO (Chassot et al., 2012; Pillai, 2012). As a result, after the 2000s fishing hours and catches per unit effort also declined. For example, in Mozambique about 51 purse seine vessels applied for licenses in 2007, whereas in 2014 this number dropped to 22 (Chacate and Mutombe, 2018). Despite regional and international efforts to decrease piracy in the Mozambique Channel (Pillai, 2012; Bergeron, 2014) the FPAs with the EU have not been renewed since 2014 (Chassot et al., 2019). In addition to piracy, the FPA negotiations have been affected by a lack of agreement on transparency clauses that would allow Mozambique to improve its monitoring of catches by EU vessels (Davies and Markides, 2019). The government of Mozambique continues to negotiate sustainable (i.e., ecologically and socioeconomically sustainable) FPAs with foreign fleets, although the number of purse seiners fishing in domestic waters dropped to eight in 2015 and to four in 2018 (Chacate and Mutombene, 2019). The lower number of industrial boats targeting tuna may not be the only reason why catches have declined. Factors such as overfishing (Campling, 2012) and changes in oceanographic conditions may have also played a role. Increased oceanic warming (Popova et al., 2016) may induce climate change with implications on the seasonal migration and aggregation of tropical tuna in the Mozambique Channel. For example, species are predicted to shift their aggregation toward southern and temperate waters by the end of the century (Dueri et al., 2014; Marsac, 2017) or displaced elsewhere and moving to deep water in the ocean (Monllor-Hurtado et al., 2017). These changes ultimately may have implications on fleet behaviour and the strategies they adopt to keep fishing profitable. On the other hand, even if stocks have declined, the CPUE has not shown clear signs of decrease yet. In both sources of purse-seine data used here, the CPUE has been relatively stable since the beginning of the 1990s, with a slight increasing trend in the last two to three years of the time series, possibly a result of fewer boats fishing Mozambican waters and/or improved technology.

Although they are not affected by piracy, small-scale fishers also noticed a decline in tuna catches and perceived a decrease in the size of individual tunas (assessed here by the recollection of the largest tuna ever caught). However, small-scale and industrial fishers, in general, do not compete over the same fishing grounds (there is likely some competition happening in Region C – surprisingly the area where purse seine activity is lowest), but they do compete over the same stocks, given that there is a single stock for each of the three tropical tuna species in the Indian Ocean (IOTC, 2021). Thus, if there were a real decrease in the tuna stocks exploited by foreign fleets, it would be expected to cause a similar decline among local small-scale fishers closer to the coast (Hampton, 1991; Kleiber, 1991; Leroy et al., 2016). The fact that small-scale fishers noticed such a decline reinforces the hypothesis that the decline in industrial fisheries is not entirely due to fear of piracy. Indeed, recent IOTC assessments of yellowfin tuna have shown that this species is overfished, and that overfishing continues to occur (IOTC, 2018; IOTC, 2021). Other species, such as bigeye tuna are subjected to overfishing, although the stock is not overfished. Skipjack seems to be in better condition, but the probability that the species is either overfished or that overfishing is occurring is close to 50% (IOTC, 2018; IOTC, 2021). Additionally, fishers within the same category compete with one another, as is the case for small-scale fishers within a given region who compete to ensure their income and livelihoods. Nevertheless, the lack of data (e.g., tagging, species size and weight composition information) makes it difficult to elucidate and quantify the magnitude of interactions between fishing sectors and among fishers in the same sector (Kleiber, 1991; Leroy et al., 2016).

It is also worth noting that, despite the decreasing maximum weight observed by fishers with respect to the largest fish ever caught, a significant portion of small-scale fishers (<45%) consider that tuna populations have not been declining and that their decreasing catches are a consequence of limited technology. According to these fishers if they had access to better gear their catches would improve. They would like to increase their effort and/or efficiency to make up for their growing losses, which is a strategy that many fisheries around the world turn to (Damasio et al., 2016). This strategy, often stimulated by governmental subsidies, is not only just a short-term solution, but also tends to worsen the stock situation (Sumaila et al., 2010; Sumaila et al., 2016). This misunderstanding of the causes behind stock depletion and the lack of capacity to find alternative resources to make up for decreasing incomes (e.g., access to better markets) are related to multiple factors, including the literacy barrier. Cognitive limitations due to poor or limited education can hinder fishers access to financial credits, economic diversification, and market information that would allow them to negotiate better contracts for fish products. (Fatunla, 1997; McGoodwin, 2001; Maddox, 2007).

Although the EU, NEIPS, and regional purse seines fleets have brought some economic benefits to Mozambique, mostly in the form of fees paid to the government, they had limited impacts on other socioeconomic levels. For example, between 2006 and 2017, the average annual contribution from foreign industrial tuna fleets to the national fisheries sectors was about 18% of €2.95±1.02 million, gathered from overall fisheries licencing fees (Afonso et al., 2017). Many African and developing coastal countries have used fishing agreements to strengthen their governance, by improving the sustainability and profitability of their accords with the developed world (Barclay and Cartwright, 2007; Mailu et al., 2015). Countries such as the Seychelles, Mauritius, and Madagascar have, for instance, demanded national prioritization of port transshipments, tuna and by-catches species landings, employment of national fishers, establishment of fish processing units, and the development of a national industrial tuna fleet (Lecomte et al., 2017b). Canneries alone, which were established to process tuna purse seine catches, generated about €5.6, €56.32, and €76.05 million for Madagascar, Seychelles and Mauritius in 2016, respectively (Lecomte et al., 2017b), whereas Mozambique, in that same year made about €0.65 million: only 7% of which was from tuna added value products, and the remaining from licensing fees (Afonso et al., 2017).

In states where tuna is transshipped, there can be multiple benefits, including jobs and improved food supply, as observed, for example, in Tuvalu, Solomon Islands, and Marshall Islands (Barclay and Cartwright, 2007; James et al., 2018) and some WIO region countries (e.g., Maldives, Seychelles, Mauritius, Madagascar, etc.) (Lecomte et al., 2017). A decree (nº 74/2013) published in 2013 by the Mozambican government (Ministers-Council, 2017) has yet to be enforced, but it could potentially improve local socioeconomic conditions by demanding that transhipments, landings, and fish processing take place in the country. This decree is also expected to enforce the requirements for scientific observers onboard, data collection systems, and the employment of Mozambican citizens on international boats; aspects that were required, but not fulfilled, in previous FPAs.

If well implemented, the benefits of agreements could partially offset the current loss of FTE jobs (e.g., one or two weeks without fishing per month) among small-scale fishers due to adverse oceanic and coastal environmental conditions for fishing while improving statistical data. Currently, Mozambique has been following the path of other developing tropical small-scale fisheries (Fatunla, 1997; Pauly, 1997) whereby its catches are landed out of urban centres and markets and without the use of official national ports. If industrial tuna fisheries were to tranship and land their fish products in national ports, these additional jobs could be occupied by some of the family members of fishers without interfering in the dynamics of SSF villages. This already happens, for example, with industrial shrimp fisheries (Santos, 2007). Similar positive socioeconomic interactions have also been noted between industrial tuna fleets and SSFs in some of the Pacific Islands, specifically in Tuvalu (James et al., 2018).

FPAs between distant water nations and other African nations have also been criticized for promoting potential overfishing (Nagel and Gray, 2012; Augustave, 2018) and for either a lack or inconsistent fisheries data collection and reporting to IOTC for stock assessment and management advice (Otterlei, 2011; IOTC, 2018). Proposals to adopt sustainable fishing partnership agreements (SFPA) have been discussed in the literature, and they include the protocols, provisions and recommendations by the IOTC (e.g., IOTC, Resolutions: 17/01; 18/01 and 19/01) on tuna and tuna-like species (Augustave, 2018; Davies and Markides, 2019). Despite the fact that several coastal states have tried to follow the IOTC recommendations, the SFPAs have been hampered by the difficulty of competing with subsidized tuna fleets (Grynberg, 2003; Arthur et al., 2019; Davies and Markides, 2019). For example, subsidies maintain the overfishing of yellowfin tuna in the WIO region, including the Mozambique Channel, which would be unprofitable otherwise (Arthur et al., 2019). Mozambique is one of the developing states where tuna fishing is carried out by subsidized foreign industrial fleets with FPAs access (Grynberg, 2003; Arthur et al., 2019), whereas local SSFs targeting tropical tuna are subsidized by microcredits provided by the national government (Benkenstein, 2013).

The socioecological interactions observed in this study, in locations where industrial fleets and SSFs compete for the same stocks, have been reported elsewhere (Kleiber, 1991; Hampton, 1991). In Mozambique, specifically, there has been an attempt to regulate this competition by geographically separating the activities (as per the national fisheries law nº 23/2013) and by limiting SSFs to up to 12 nm offshore, where the industrial fisheries jurisdiction begins. Industrial purse seine fleets seem to monitor and manage their FADs efficiently (Soto et al., 2016) by controlling fishing areas and minimizing the possibility of direct interactions and impacts with SSFs. However, the same stocks are being exploited by both fleets, especially in the high SSF fishing season (Campling, 2012; Kaplan et al., 2014; Obura et al., 2018). In the low season, when there is no industrial fishing in the region (Campling, 2012; Obura et al., 2018) competition over resources probably occurs among SSFs. In developing countries, it is common for SSFs to target the resources in greatest abundance (easier to catch) and profit to maximize income and livelihoods (McGoodwin, 2001; Tietze, 2016). Although it is seasonal, SSFs income in the high season was comparable to the income paid to staff working in the public fisheries sector (not including high paid managerial jobs) for the period 2017-2019 (MEF et al., 2017; MEF et al., 2019). Tuna continues to be a profitable commodity for small-scale fishers and consequently tuna fishing continues to attract newcomers (as perceived by the small-scale fishers interviewed). This leads to increases in the fishing effort (Gordon, 1954; Panayotou, 1982; Pitcher and Lam, 2015) and intensifies competition (Campling, 2012).

Socially, small-scale purse seine fleets provide more jobs in Mozambique (61% of total fishing-related jobs) than gillnet and handline fishing. The regional distribution of fishing gear i.e., small purse seine and gillnets in north (region A and B) could be related to the traditional and cultural fishing system acquired from ancients or experience transmitted through generations in the communities (McGoodwin, 2001). With a total of 954 jobs generated by SSFs targeting tuna in the three regions analysed it is estimated that Mozambique requires ~160 small-scale fishers to land a tonne of tuna. As a comparison, the Maldives requires 180 fishers, Iran 956 fishers, and the EU industrial purse seines in the WIO region, only six people (Lecomte et al., 2017a; Lecomte et al., 2017b). These figures do not include the extensive value chain of small-scale fishers with an intricate web of middlemen that in many cases distribute the fish from the villages to the main cities and neighbouring countries.

5. Conclusions

The findings of this study contribute to a better understanding of the ecological, economic and social pillars of tuna fisheries sustainability in Mozambique. In terms of ecological sustainability, there is evidence that the local catches of tropical tuna in Mozambique have been declining over the last 10 years. Although part of this decline can be attributed to piracy, which has forced some fleets out of the region, real stock declines cannot be dismissed, especially considering that small-scale fishers, who are not subject to piracy, have also reported it. As a precautionary approach, improved management measures should be considered at both local and international levels, along with improved fisheries data collection and support of scientific research. Economically and socially, there is room to make fishing agreements more beneficial to the Mozambican population, by ensuring that both transhipments and processing occur domestically. This would generate more jobs and ensure that part of the profits and revenues circulate within the country and improve accountability. Efforts should also be made to actively enforce the exclusion of industrial fisheries from the reserved nearshore fishing grounds (<12 nm) to decrease potential future conflicts. In addition, the fish harvested by small-scale fishers should be incorporated into official national statistics.

This study also suggests that competitive interactions among industrial fleets and SSFs over tuna species have possibly been contributing to stock decline, given that the same stocks are being harvested in different regions of the WIO and by all types of gear. Better policies and a stronger governance that facilitates and promotes landings, transhipments, and tuna and by-catch processing in Mozambique will likely improve the social and economic outcomes of both SSFs and the Mozambique fishing. Future agreements should be socially and ecologically fair and supported by sound management advice on the sustainability of exploitation rates. Economic diversification and improved literacy rates among small-scale fishers should be promoted to better prepare them for possible resource failures, whether it be caused by overfishing, climate change or any other factor. Although preliminary, this is the first study that adopts an integrative approach to understanding the effects of having economically important stocks shared by distinct types of fisheries, especially on the more vulnerable link of the chain, local small-scales fishers.

Acknowledgements

This study was partly funded by a PhD scholarship from the World-Wide Funding (WWF, Agreement #R27) to the first author to carry out his study at the University of Alicante (Spain). Special thanks to Eduardo Mondlane University for environmental working and support field work provided during the research activities. The acknowledgement is extending to Dr Jack Littlepage, Emeritus Professor from University of Victoria (Victoria Canada) for Technical English Language review provide to this article.

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Socio-ecological and economic aspects of tropical tuna fisheries in the Mozambique Channel~~ – Insight from Mozambique~~

Abstract

Industrial and small-scale tuna fisheries in Mozambique may compete over the same resources, which has potential socio-ecological impacts. ~~We~~ The two types of fisheries were investigated ~~these two types of fisheries~~ by characterizing their catch trends, types of interactions, number of people they employ and revenues. Commercial landings, logbook data, and all previously established tuna Fishing Partner Agreements in the country were analysed, as well as data collected from interviews with small-scale fishers. A declining trend in catches was ~~has been~~ observed in the industrial fisheries sector, which was also ~~has also been~~ perceived by small-scale fishers, and suggests that there is some competition between these two sectors for the same tuna stocks, even when these stocks are targeted in separate grounds. Whereas the small-scale tuna fisheries sector provides thousands of local direct and indirect jobs and high economic benefits for fishing communities, the industrial fisheries sector may ~~not~~ only be ~~so~~ more economically advantageous to Mozambique, ~~especially~~ if Fishing Partner Agreements are ~~not~~ improved and enforced. Although maintaining non-overlapping fishing grounds between industrial and small-scale fisheries may be positive for the fishers, it could also be a cause of major stress for the tuna, which are exploited relentlessly.

Keywords: *Purse seine tuna fisheries, small-scale tuna fisheries, fleet interactions, shared stocks, Western Indian Ocean fisheries*

1- **Introduction**

The story of how tuna fishing in Mozambique began starts in the second half of the 1970s, when the Soviet Union began a research program on large pelagic fish (Simões, 1984a) using a drifting longline to map the space use and seasonality of tuna schools. In 1983, chartered vessels from Cape Verde began experimental fishing with pole and lines and live bait (Simões, 1984b). With promising r~~R~~esults ~~from both the Soviet Union research and the experimental fishing were promising. Consequently, between the end of 1983 and the beginning of 1984 Mozambique~~ Mozambique issued commercial fishing licenses to vessels from France, Portugal, Spain and the Soviet Union , between 1983 and 1984 (Simões, 1984b). This was the same~~, thus following the~~ path of other developing countries, who placed tuna exploitation in the hands of international fleets through environmentally and socioeconomically dubious fishing agreements (Havice and Reed, 2012).

The first fishing partner agreement (FPAs) between the European Commission (EC) and Mozambique was signed in 1987 (EC, 1987). Authorized European vessels were subjected to pay the Mozambique authority fishing licence fees, equivalent to 1,000.00 European Currency Units (ECU, i.e., 1 ECU is equivalent to1€), for the right to catch 50 tonnes of tuna in waters under the jurisdiction of Mozambique (EC, 1987). ~~For every ton of fish declared to have been caught in Mozambican waters, the European fleets were required to pay 20.00 ECU in fees.~~ This ~~first fishing~~ agreement was terminated in 1993 by ~~the Mozambican authority~~ Mozambique, who deemed that the agreement was disadvantageous toward the development of the local fishing sector (EC, 2003).

A ~~In 1999, the EC resumed conversations with Mozambique on tuna fishing and led to the drafting of a~~ second agreement with the EC~~, which~~ was implemented in 2004 for a period of three years with. ~~Compared to the first FPA signed in the 1980s, this latest agreement included increased benefits to Mozambique, such as an increase in compensation fees. F~~fishing license fees ~~in 2004~~ were set at €3,000.00 for tuna seiners and €1,500.00 for long liners, corresponding to 120 tonnes and 60 tonnes of tuna, respectively.~~, and a small fraction of by-catch (e.g., billfish, dorado) caught in Mozambican waters (EC, 2003). The fee per vessel for~~

~~each tonne of fish declared to be caught in Mozambican waters was set at €25.00.~~ An updated third agreement~~, which renewed the protocol,~~ was established between 2007 and 2011, and licence fees were set at €4,200.00, equivalent to 120 tonnes, for tuna seiners (~~equivalent to 120 tonnes~~) and €3,500.00, equivalent to 100 tonnes for longliners (EC, 2007). ~~(equivalent to 100 tonnes~~), ~~plus €35.00 per tonne of either tuna or by-catch caught in Mozambican waters (EC, 2007).~~

~~The second and third agreements were apparently satisfactory for Mozambique given that after the agreements were up a~~ A fourth agreement ~~one~~ came into force in 2012 for another three years. This ~~The fourth~~ agreement included 1) compensatory fees to develop the fishery sector (e.g., construction and expansion of infrastructure, training of fisheries staff, increased and improved fisheries monitoring and surveillance, and increased capacity for scientific observation and data collection,~~, among other actions related to fisheries management),~~ ~~and~~ 2) details of who should pay for the ~~logistical expenses of having~~ scientific observers onboard (whose presence had been a requirement since the first agreement), ~~in addition to stipulating~~ and 3) an increase in licensing fees (purse seiners: €5,100.00 for 146 tonnes, longliners: €4,100.00 for 118 tonnes~~, and €35.00 for every extra tonne~~) (EC, 2012). This agreement was renewed in 2015, however licenses were mostly limited to longline vessels (>25), with less than 10 licenses issued to purse seiners (Chacate and Mutombe, 2018). .However,~~ since 2018~~ Mozambique has not issued licenses to purse seiners since 2018, as the country seeks to negotiate more profitable fees with international industrial tuna fisheries.

~~Despite the existence of fishing~~ In spite of these agreements,~~ since 1987, which established fees per tonne of fish caught,~~ Mozambique only began recording totan annual catches (www.mimaip.gov.mz)~~national fisheries statistics~~ in 2005,~~ and these statistics are limited to total annual catches (www.mimaip.gov.mz). The update and~~ ~~r~~Renewal of ~~consecutive~~ agreements did not necessarily mean that the terms were fully met. ~~For example, the~~ The requirements to provide jobs for Mozambicans, to land and perform transhipment catches in national ports (EC, 1987; EC, 2007; EC, 2012), and to have Mozambican scientific observers onboard ~~fishing vessels~~ to monitor and collect data (EC, 1987; EC, 2003) were never implemented~~met~~. ~~Whereas I~~I~~i~~n

Mozambique jobs are rarely documented and benefits are mostly limited to fishing license fees (Afonso et al., 2017)~~,~~whereas in the other Western Indian Ocean (WIO) countries (e.g., the: Seychelles, Mauritius, and the Maldives~~, etc.~~) EU purse seine fleets generate more than 4000 jobs, corresponding to estimated economic benefits of between €22 and €40 million in 2014 (POSEIDON et al., 2014).

In ~~Although industrial tuna fisheries do generate some jobs in~~ Mozambique, most of the ~~fishing~~ tuna--related jobs ~~in Mozambique~~ are in ~~related to~~ the small-scale fisheries (SSFs) sector, which does not follow any sort of agreement. For example, in 2012, almost 37,200 licenses were issued for SSFs with ~~about~~ 130,000 fishers directly involved in catching tuna (neritic and tropical tuna) and tuna-like species (Chacate and Mutombe, 2018).~~ Additionally, the SSFs tuna value chain generates jobs in manufacturing boats and gear, and various levels of middlemen. The latter, in contrast to fishers and manufacturers, include both women and men~~. As is the case with industrial fisheries, tuna SSFs also suffer from a lack of statistical information and sampling programs to record catch and effort data. The situation is even worse when it comes to information surrounding the socioeconomic aspects of SSFs, and existing knowledge is either merely anecdotal~~anecdotic~~ or only available in the grey literature.

~~Given that an overall picture of the social-ecological impacts of tuna fisheries is still lacking in Mozambique, t~~This study describes the interactions between the industrial fisheries and SSFs sectors in Mozambique coastal waters. It ~~For example, it~~ is clear that SSFs target the same tuna stocks as industrial fisheries~~ (i.e., tuna are highly migratory species)~~, but due to the technological limitations~~ of this type of fisheries~~, the grounds of the first are closer to the coast (Ruttan et al., 2009), which by law ~~(<12 nm)~~ are not accessible to industrial fisheries (Mozambique Fisheries Law nº 22/2013). It is not known if the <12 nautical mile limit is enforced | w~~W~~hether these limits are enforced. ~~or not is not known.~~ Given that tuna stocks are shared~~,~~ both types of fisheries are expected to feel the effects of stock declines in the event of overexploitation or other causes (e.g., natural fluctuations, climate change). The extent of job creation by each fishing sector is also unknown in Mozambique. T~~hus, t~~o fill these information gaps~~,~~ data from industrial purse seine catches in Mozambique’s Exclusive Economic Zone (EEZ) obtained from external databases were combined with career-history interviews with small-scale fishers. This information will contribute to improving the scientific knowledge surrounding tuna fishing in the region. Additional and better knowledge can contribute to supporting a revision of the FPAs and assessing the trade-offs between Mozambique and foreign industrial fleets by using a precautionary approach to solve some of the pitfalls in ~~how~~ management of tuna fisheries ~~are managed~~ in Mozambique ~~(de Bruyn et al., 2012)~~.

2. Methodology

2.1 Study location

The Mozambican coast is located on the west side of the Mozambique Channel (Figure 1). In this area, both I~~i~~ndustrial and small-scale fisheries target different species of tropical tuna in the region~~,~~ which include *Katsuwonus pelamis* (Linnaeus, 1758; skipjack tuna - SKJ) ~~*Katsuwonus pelamis* (Skipjack tuna - SKJ),~~ *Thunnus albacares* (Bonnaterre, 1788; yellowfin tuna - YFT) ~~*Thunnus albacares*~~ (~~Yellowfin tuna - YFT~~), and *Thunnus obesus* (Lowe, 1839; bigeye tuna - BET) ~~*Thunnus obesus*~~ (~~Bigeye tuna - BET~~). Foreign industrial distant-water fleets harvest tuna with the use of hand lines, longlines and purse seine gears. According to data provided by the Spanish Oceanographic Institute (IEO) and the Indian Ocean Tuna Commission (IOTC), the main tuna fishing grounds in Mozambican waters for purse seiners extend ~~primarily~~ from the centre to the northern part of the country (latitude <20S) (Figure 1). Data retrieved from IEO correspond to the logbook records of Spanish purse seine fleets, whereas data gathered from IOTC include all data from purse seine fleets who have FPAs with Mozambique (e.g., EU, the Seychelles, Mauritius, the Mayotte Islands, among others) (see data collection section for further details).

To ~~Thus, to~~ access the eventual socioeconomic impacts of both the industrial and small-scale fisheries sectors~~,~~ sharing the same stocks, small-scale fishers were interviewed in four ~~three~~ provinces. These were~~,~~

grouped into three regions:~~:~~ Cabo Delgado - Region A (northernmost villages from Palma, Mocimboa da Praia, and Ibo Island), Nampula – Region B (center-north villages in Memba, Nacala, and Mozambique Island), and Inhambane and Maputo provinces – Region C (southernmost villages in Inhassoro, Tofo Beach and Inhaca Island) (Figure 1). ~~In all the villages studied,~~ F~~f~~ishing in these villages is carried out with ~~row~~ canoes or wooden and fibre sailboats that are rowed, propelled or equipped with a small outboard engine of 15-50 HP. The gear~~s~~ used ~~are~~ is mainly hook-and-line (with sardines used as dead bait), gillnets, and small manually-operated purse seines. The fish caught by small-scale fishers are either traded locally or kept for self-consumption, thus supporting local food security and livelihoods.

The coastal zones in Mozambique are characterized by a tropical climate ~~with two~~ marked by ~~seasons (Hoguane, 2007):~~ a wet season, from November to April, ~~-~~and a dry season, from May to October (Hoguane, 2007). T~~he wet season is related to the summer monsoon, whereas the dry season is linked to the winter monsoon, and the precipitation peaks are timed to the transition monsoon (Hastenrath, 2015).~~ The tuna fishing, ~~season,~~ for both SSFs and industrial fisheries, is very seasonal and typically begins in late February (wet season) and ends around the beginning of July (dry season) (Campling, 2012, Obura et al., 2018; Chassot et al., 2019).

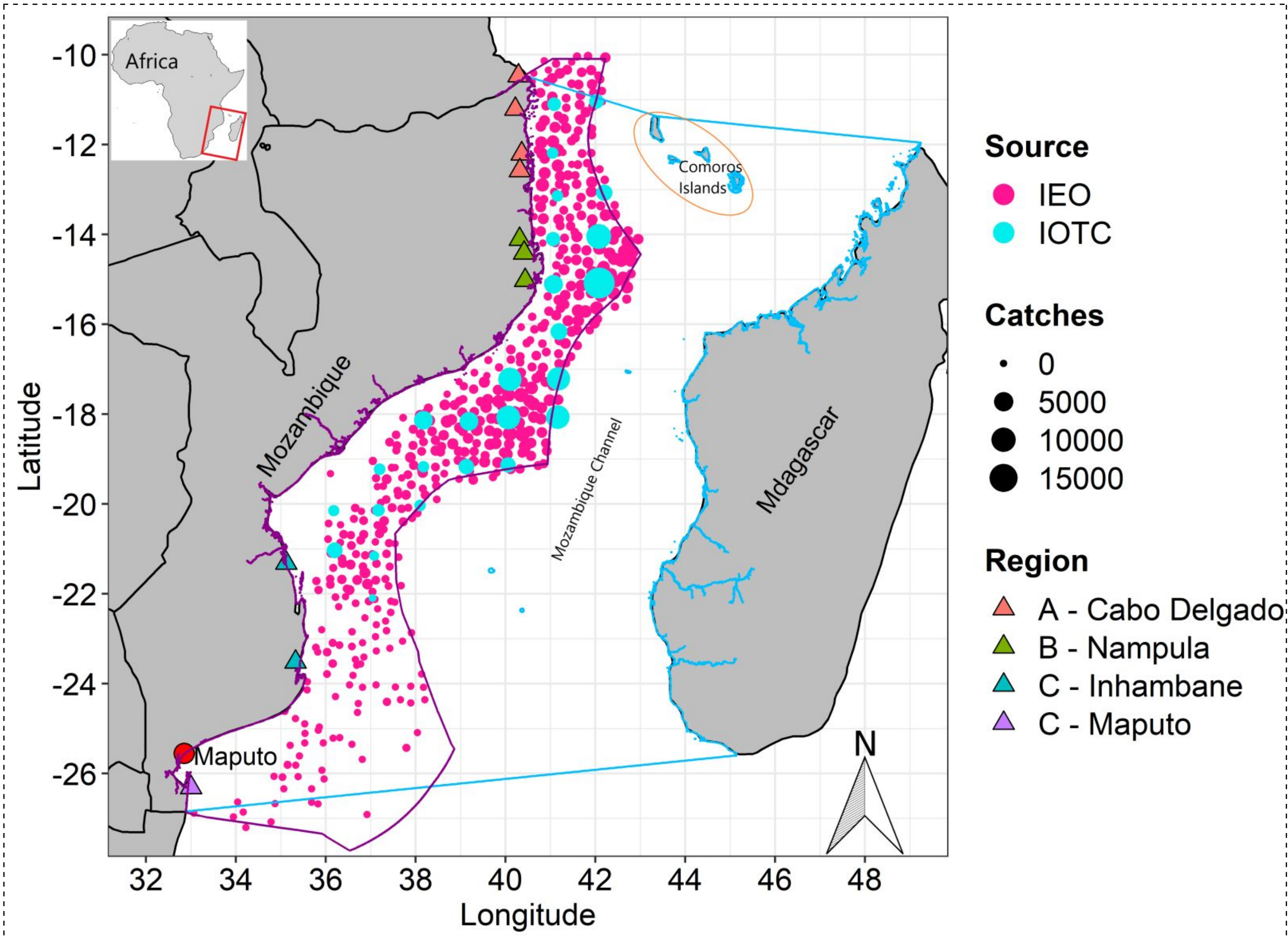

Figure 1. Map of the study area showing the distribution of tropical tuna (circles) catches, in tonnes by industrial purse seine fisheries, in the Mozambique Economic Exclusive Zone (delimited by the magenta line), as part of the Mozambique Channel (area delimited by the deep sky-blue line) for the period 1983 to 2014. Data were spatially aggregated as the sum of a 1/4º grid cell. The triangles mark the coastal villages in each region (A, B and C) where interviews with small-scale fishers and fishing authorities took place. Catches correspond to the tropical tuna species (SKJ - *Katsuwonus pelamis*, YFT- *Thunnus albacares*, and BET - *Thunnus obesus*). IEO logbook data refers to purse seine Spanish fleet fishing. IOTC (purse seine fleets from the EU, the Seychelles, and Mauritius, among others) for commercial data was gathered from all purse seine fleets that fished in Mozambican waters during study period. Shapefiles for Mozambique EEZ and the Mozambique Channel were accessed from https://www.marineregions.org. The red dot in the southern coast of Mozambique indicates Maputo, the country's capital.

2.2. **Data Collection**

2.2.1 ***Macro-scale data from purse seine tuna fishing***

Total landing commercial data were retrieved from the Indian Ocean Tuna Commission (IOTC) (www.iotc.org), the tuna regional fisheries management organization for the Indian Ocean convention area. We did not use the national data collected from 2005 on, as this was lacking in detail (total annual catches only). The~~se~~ IOTC catch data were stored by monthly over the period ~~between~~ 1983 and 2014 at a 1º x 1º spatial resolution in a database for the FAO fishing zone 51. In addition to catches per species, the data file also included information on fleet, fishing grounds, date (year and month), fishing hours and, in the case of purse seiners, and set type (i.e., whether fishing was conducted on Free Swimming Schools - FSC or on Fish Aggregating Devices - FAD ~~—~~(any type of floating object used to aggregate tuna). Furthermore, daily sets from logbook data for Spanish purse seiners covering the same spatial and temporal resolution were provided by the Instituto Español de Oceanografía (IEO) and were used to compare and complement tuna catch trends. The logbook data were more representative than the IOTC data because they were collected through a scientific sampling observation programme carried out by the IEO. Logbook data also included information on catches ~~per~~by species and fishing mode (FSC and FAD), fishing hours, date (year, month, and day of the fishing operation), and location of the fishing activity (i.e., longitude and latitude), and the fishing sets were aggregated as the sum of ¼º resolution. To estimate the Catch Per Unit Effort (CPUE), total catch per year was divided by total fishing hours.

To describe the socio-economic issues facing tuna fisheries over the last three decades on a macro-scale, publications from the Mozambique Ministry of Fisheries Authority database (www.mimaip.gov.mz) were revised and available data were retrieved from the European Union database (www.eu.org) to access the Fisheries Partnership Agreements (FPAs) between Mozambique and the EU. Both peer-reviewed (~~e.g.,~~ Chassot et al., 2019) and grey literature, including technical and project reports about the socio-economic aspects of fisheries in Mozambique were also reviewed (~~e.g.,~~ Gorez, 2003; EC, 2007; Kusi, 2008; EC, 2012; POSEIDON et al., 2014; Afonso et al., 2017; Lecomte et al., 2017a; Lecomte et al., 2017b; Mutombene et al., 2017; Chacate and Mutombe, 2018), together with dissertations (e.g., Otterlei, 2011; MANACH, 2014; Mendiate, 2016; Augustave, 2018). Revenue data were extracted from the FPAs. Nevertheless, information regarding job creation for Mozambicans within industrial tuna fisheries segments ~~(extractive, transhipment to processing) was hardly found.~~ very limited.

*2.2.2~~1~~ **Interviews with small-scale fishers***

Interviews with small-scale fishers were carried out between 2017 and 2018 in 10 villages in three different regions along the Mozambique coast (Figure 1). Additionally, the provincial and local fishing authorities in each village were contacted both during the scoo~~o~~ping phase and throughout the course of the research to discuss the data gathered from fishers. ~~During the scooping phase it emerged~~Scoping revealed that small-scale fishers mostly target tuna in the northern and southern parts of the Mozambique coast, but rarely in the central region. Therefore, the study design included seven villages in the north (10ºS - 15ºS), three villages in the south (21ºS - 26ºS), and no sampling in the centre region,, between 15ºS and 21ºS (Figure 1).

~~In the villages, a~~A semi-structured face-to-face questionnaire was ~~applied,~~utilized ~~given that this method allows flexible and interactive discussions between the interviewer and interviewees~~ (Johannes et al., 2000; Wengraf, 2001; Babbie, 2012;). The questionnaire had four parts (Appendix S1): personal information (e.g., age, experience, and education), tropical tuna catches (e.g., size composition of catches, seasonality, gear types, fishing equipment and techniques), socioeconomic aspects of tuna fishing (e.g., revenue, employments, value chain, fishing cost), and interactions between SSFs and industrial purse fisheries (e.g., types of interactions, use of FADs, potential impacts). The interviewee selection process relied on ~~Methods for this study included~~ a combination of expert-opinion~~ surveys~~, key informant interviews, and snowball sampling as per recommendations from previous authors (e.g., Huntington, 2000; McGoodwin, 2001). Expert opinion surveys are a data collection technique in which the community council selects the most knowledgeable or experienced people in the village from a pool of potential participants to be interviewed ~~by the researcher~~ (Huntington, 2000). Here~~In the case of this study, whenever applicable~~, the community helped identify key ~~informants~~participants, who were those that had more specific and detailed information on the catch of tropical tuna ~~(Tremblay, 1957; McGoodwin, 2001)~~. Each interviewee suggested the names of other local experts, which corresponds to the ~~is a method known as~~ “snowball sampling” technique (Huntington, 2000; McGoodwin, 2001). Snowball~~This~~ sampling method was especially efficient given that less than 10% of the fishers in each study village target tropical tuna. Furthermore, fishing authorities, village leaders, and key participants ~~informants~~ were initially consulted to recommend expert tuna fishers who might be available to be interviewed, given the lack of official fisher databases in both the villages and at higher levels.

The interviews were either conducted at fish landing sites or at fishers’ homes. Prior to beginning the survey, fishers were ~~explained~~ told about both the goals of the research and what was expected of them. Only fishers with a minimum of 5 years of experience targeting tuna were ~~approached~~considered. Interviewees were also explained that they had an option to participate or not, to leave the interview at any moment, or not to respond to specific questions. The interview proceeded after oral consent was obtained from the interviewee. ~~The best times to conduct interviews were after fishers had finished their daily routines, when they were relaxing or repairing their nets, or during their days off in their villages.~~ Local fishing leaders ~~(i.e., the head of the local fishing council)~~ were approached first in each of the study fishing villages to authorize the survey and to help identify potential experienced tuna fishers. Prior to applying the questionnaire, fishers were asked to freely talk about “good and bad” days of tuna fishing, both from the present and past. Only after this exchange ~~moment~~ were fishers shown printed colour pictures and leaflets of the three tropical tuna species to make sure they were correctly identifying the species and the ones they have targeted. The interviews proceeded after it was confirmed that the fisher being interviewed had caught at least one of the three species shown. A technician representing the fishing authority and leaders of the community fishing council helped ensure the trust and collaboration of fishers for the interviews, which lasted, on average, 25 to 35 minutes.

A total of 101 fishers were interviewed, aged between 19 and 73 years old (41 ± 12, >32% between 41 and 50 years old), and who had been fishing for 5 to 55 years (21± 12, 80% ≥ 10 years of experience) (Appendix S2, Figure 1). The sample was balanced, with 33 fishers from region A (9 gillnetters, 14 hand liners and 10 small seiners), 35 from region B (5 gillnetters, 10 hand liners and 20 small seiners), and 33 fishers from region C, who all fished with handline. The literacy level of the interviewees was low, with 91.4% either illiterate or with less than four years of schooling. Contrary to industrial fishers, small-scale fishers rarely focus on a single species or even group of species, such as tunas.

2.3~~4~~ Data analysis

Macro-scale industrial purse seine data from the Mozambique EEZ were ~~subset~~ gathered from each database using the QGIS 3.4 software (QGIS Development Team, 2018), aggregated to a ¼º x ¼º spatial resolution, and exported as a *csv* file for posterior statistical analyses in the R statistical software (R Core Team, 2018). The packages ‘ggplot2’ (Wickham, 2009), ‘mgcv’ (Wood, 2006), and ‘polynorm’ (Venables et al., 2016) were used to view and model fleet behaviour, tuna catch trends and CPUE. Three-degree polynomial order regressions were used, as they provided the best statistical score of goodness-of-fit (r^2) for catch trends for both logbook and commercial data. The number of people employed in fisheries and total revenues were the main social and economic indicators, respectively, for descriptive approaches of industrial fisheries.

With respect to SSFs data, it was investigated whether the largest tuna (~~kg~~kg) ever caught or seen (i.e., caught by another fisher) by fishers had changed over time, according to their own recollections of the size and year when the catch occurred (Tesfamichael et al., 2014). 'Largest individual tuna' was chosen as the ecological indicator to be recalled by fishers because tropical tuna species are often mixed with other species, including both pelagic species and neritic tunas, thus hampering fishers' abilities to understand best catches for only tropical tuna species. Referring to fisher memories is a relatively reliable strategy to estimate changes in catches (amounts and fish size) when official statistics are not available (Damasio et al., 2015). Again, polynomial regressions were used to analyse catch trends, specifically the relationship between the largest tuna ever caught and the year of occurrence.

Villages were also aggregated into regions in order to assess~~access~~ the environmental and local perceptions of fishers toward the social and economic impacts of tuna fishing in their villages. Fishers from ~~close~~ nearby villages were assumed to share similar marine environments and, therefore,~~ it was assumed that people living in these villages shared~~ similar adaptation strategies, specific behaviour, fishing cultures and self-organization arrangements rooted in the exploitation of that particular environment (McGoodwin, 2001). F-tests were applied to compare the variability of reported means for species frequently caught by fishers per month among regions~~ (Underwood, 1997)~~. Similar to the SSFs sectors in other regions throughout the world (McGoodwin, 2001), it is not easy to distinguish subsistence from commercially oriented fishing in the study villages. Thus, interviewees were clustered by gear types to allow comparisons among gear types within and among regions. Like the macro-scale descriptive analyses, the number of people employed and revenues were the main social and economic indicators considered. The monthly workload was converted into full-time equivalent jobs or employment (FTE). FTE is a unit of measurement of the average number of workers doing a specific task, in a way that makes them comparable, although they may work a different number of hours per week (ilostat.ilo.org). The unit was obtained by comparing the average working hours of the average crew using a specific type of gear (i.e., gillnet, handline or purse seine) to the average number of hours of a full-time worker in Mozambique (i.e., 1.0 FTE for a worker is equivalent to 8 hours/day x 5days/week x 4 weeks~~8 hours / day x 5 days / week x 4 weeks / month~~ ≈160 hours per month). For this study, one Mozambican full-time worker was compared to the average crew, rather than the individual, given that the result of the crew's work is collective, rather than individual, i.e., total fish landed.

Because of the heterogeneity and lack of archive information relative to investments and the operational costs of fishing within and among gear types, individual revenue was assumed to be the best economic indicator ~~recalled by~~for small-scale fishers. After the fish caught on a trip are sold, the revenue is divided among the crew according to one of three arrangements: (i) *self-fisher* - there is only one fisher, who also owns the boat and thus pays the costs and keeps the entire revenue; (ii) *team fishers* - first the daily operational cost (e.g., fuel and oil) are subtracted from total revenues, when applicable, then 50% of the remaining revenues go to the fisher who owns the vessel, and the remaining 50% is shared equally among the crew (excluding the boat owner); and (iii) *patron* - the boat is owned by a patron, who keeps 40% of the revenue (after discounting the operational costs); the remaining 60% of the income goes to the actual fisher(s).

3. Results

3.1. *Macro-scale purse seine tuna fisheries*

Industrial purse seine fisheries have been targeting tuna in Mozambican waters since 1983 (Figure 2a). Prior to this period, catches were seldom reported, ~~despite the fact that the~~ even though Russians had been researching and fishing the Mozambican coast since the mid-1970s. ~~Although Spain only began fishing in Mozambican waters two years after France, it concentrated~~ Spain accounted for most of the catches during the study period (49% of the total accumulated catches over 30 years) (Figure 2). Between 1983 and 2014, Spain and France reported total accumulated catches of 58.1 and 37.2 thousand tonnes of tuna, respectively, while~~ereas~~ the regional fleets (e.g., Seychelles, Mauritius, Mayotte) together accounted for about 10.9 thousand tonnes, and overall, the NEIPS fleets (Netherlands, Italy, Greece, Portugal, Japan, Korea, and others), accounted for almost 12.2 thousand tonnes (Figure 2b). Regardless of the fleet, the main target has been skipjack tuna (Figure 2b), which accounts for more than 65% of the total catch during the study period (YFT and BET at 29% and 5% of catches, respectively).

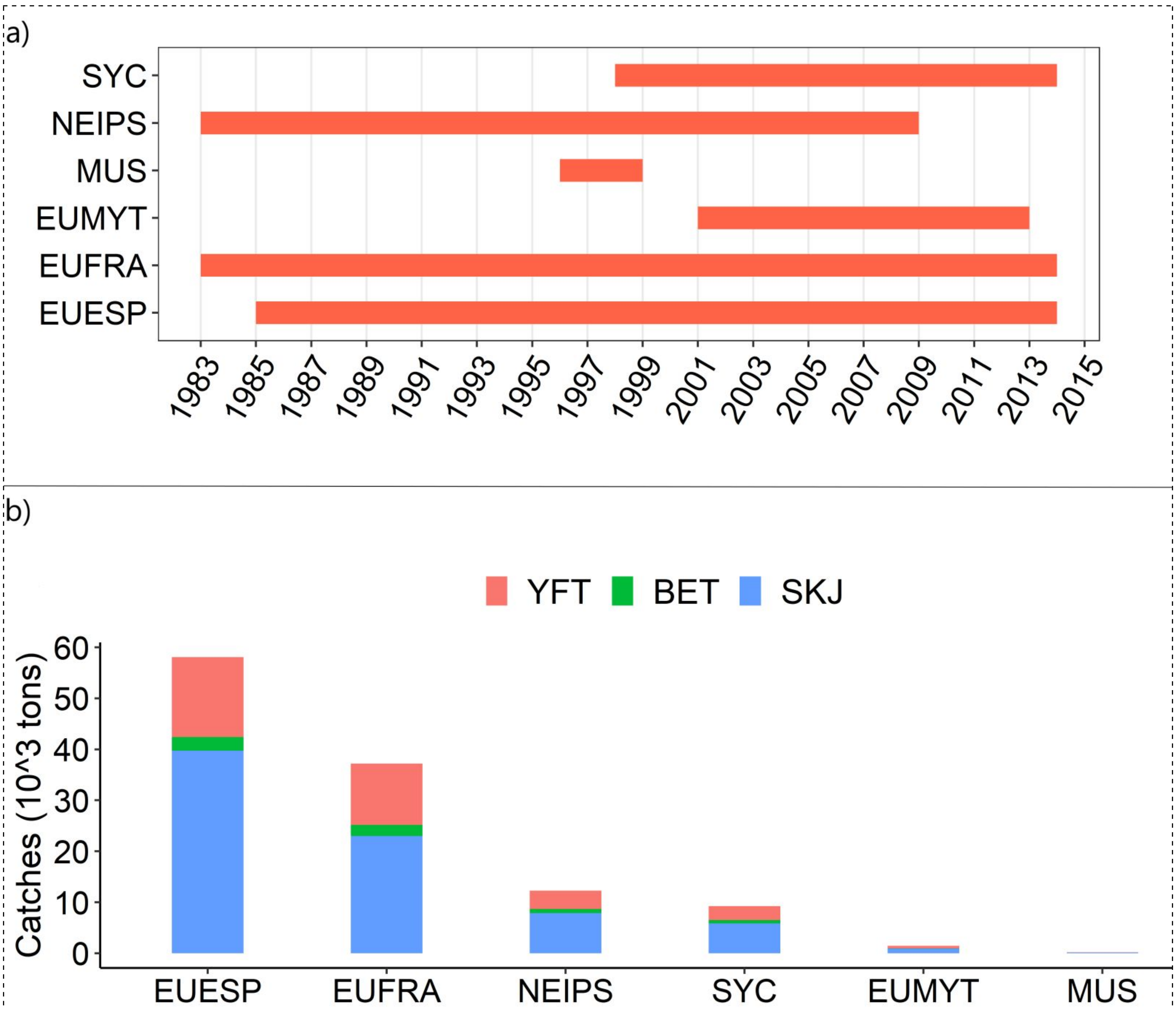

Figure 2. ~~History~~ Timeline of purse seine fleets operating in the Mozambican EEZ and targeting tropical tuna between 1983 and 2014 (a), and their respective total catches over time (b). All fleets are international: EUESP - Spanish, EUFRA - French, NEIPS - Other fleets, SYC -Seychelles, EUMYT- Mayotte Island French territory, and MUS - Mauritius fleets. BET- Bigeye tuna, SKJ - Skipjack, and YFT-Yellowfin tuna. There are no records of Mozambican purse seine fleets operating in the region.

The tuna catch trend is characterized by a semi-parabolic curve, regardless of the source of data (detailed Spanish logbook or general commercial data) (Figure 3). The Spanish purse seine logbook data shows catches increasing at a rate of 4.1~~06~~% per year between 1983 and 2000, followed by a fast decline of 7.2~~1~~% per year until 2014 (historical minimum). The overall purse seine commercial data shows a less pronounced annual increase and decrease, with an earlier ~~and the~~ decline ~~is shown to have occurred earlier~~ than ~~in~~ the logbook data. In the latter data, catches are shown to have first increased at a rate of 1.7~~.65~~% per year between 1983 and 1997, and then to have decreased at a rate of about 1.4~~.35~~% until the end of the time series (~~-~~also the historical minimum). Therefore, there is some evidence to suggest that catches have been generally declining over the last 15 to 20 years;~~,~~ however, there is a high degree of variability within each dataset, i.e., the logbook (r^2=0.51) and the commercial (r^2=0.45) data (Figure 3a-b). The CPUE showed growth rates of 13.3~~3~~% and 6.4~~1~~% for logbook (r^2 = 0.42) and commercial (r^2 = 0.14) data, respectively, between 1983 and 1998 (Figure 3 c-d), followed by some stability, and another increase in the last three years of the time series (Figure 3 c-d).

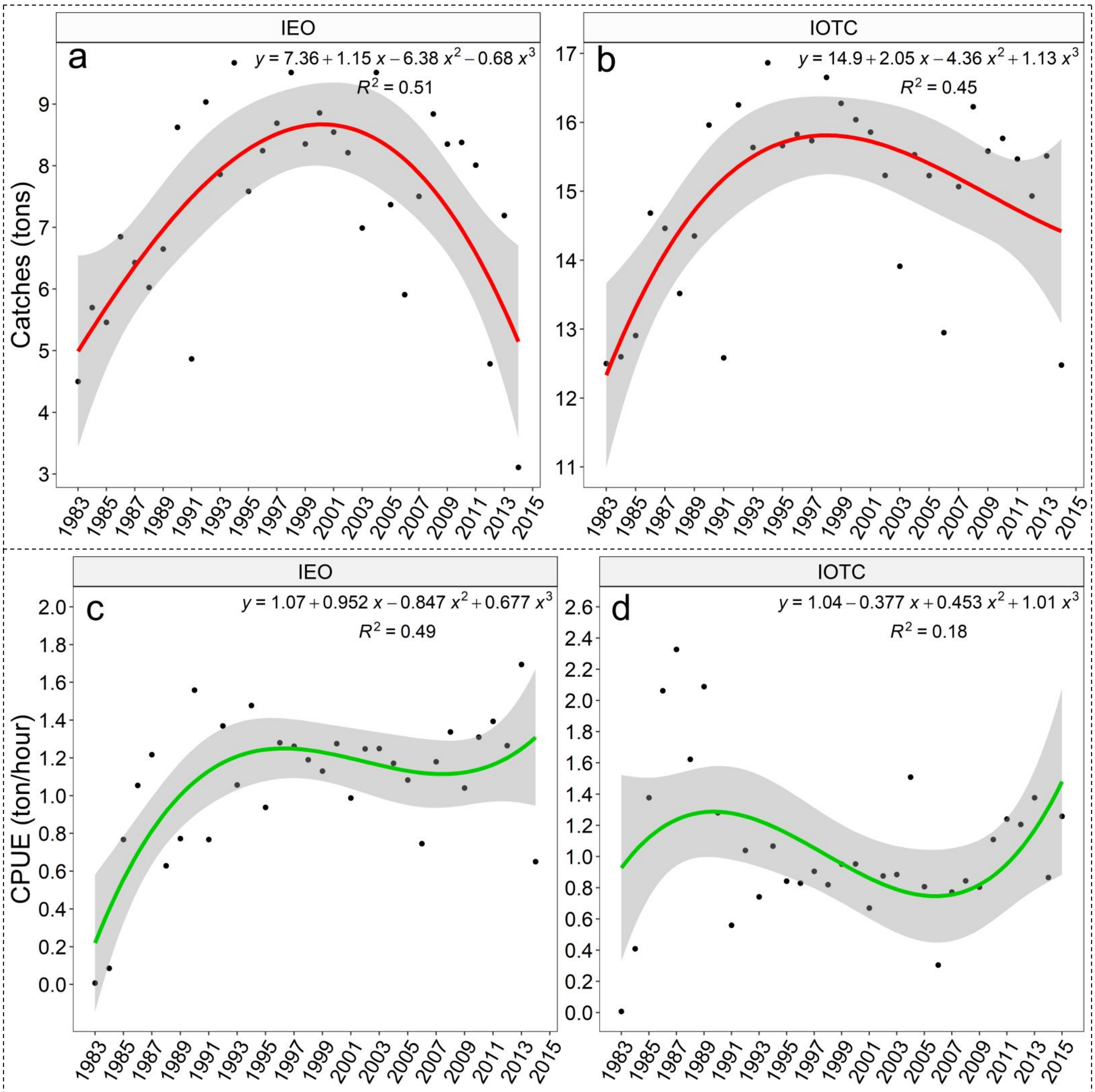
IEO
a
$y = 7.36 + 1.15\ x - 6.38\ x^2 - 0.68\ x^3$
$R^2 = 0.51$
Catches (tons)
IOTC
b
$y = 14.9 + 2.05\ x - 4.36\ x^2 + 1.13\ x^3$
$R^2 = 0.45$
IEO
c
$y = 1.07 + 0.952\ x - 0.847\ x^2 + 0.677\ x^3$
$R^2 = 0.49$
CPUE (ton/hour)
IOTC
d
$y = 1.04 - 0.377\ x + 0.453\ x^2 + 1.01\ x^3$
$R^2 = 0.18$
1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015

Figure 3– Catch trends (a and b) and catch per unit of effort (CPUE) (c and d) by purse seine fleets in Mozambique for the period 1983 to 2014. Catches are composed by the following tropical tuna species: bigeye tuna (*Thunnus obesus*), skipjack tuna (*Katsuwonus pelamis*), and yellowfin tuna (*Thunnus albacares*). Logbook data provided by the Instituto Español de Oceanografia (IEO), and commercial data provided by both the Indian Ocean Tuna Commission (IOTC). Data were transformed to a logarithmic scale to reduce the variance in order to observe trend patterns.

~~Table 1 summarises the revenues from purse seine fleets under the FPAs between Mozambique and the EU.~~

The revenues ~~contribution fees~~ from the EU fees to develop the Mozambican fisheries sector improved with every consecutive FPA (Table 1). For example, the FPAs approved in 2007 and 2012 contributed with~~reveal that the annual EU contributions to developing the fishing sector were~~ €826,400 and €1,087,100, respectively (Table 1), which corresponded to ~ $680,000 in 2007 and ~$800,000 in 2012 PPP dollar value (PPP - purchasing power parity USD). The last fishing agreement expired in 2015 and ~~to date~~ has not been renewed.

Table 1- Revenue summary for purse seine fleet under fisheries partnership agreements (FPA) between Mozambique and the European Union. Data sources: https://ec.europa.eu/fisheries and https://www.iotc.org. mt = metric tonnes. All FPAs started on January 1st and ended on 31 December ~~December 31st.~~

Item	Fishing partnership agreements signed					
Year of FPA signature	1987[1]			2003	2007	2012
Protocol agreement	~~Fist~~First	Second	Third			
Duration (Years)	3	2	13	3	4	4
Number of purse seine licenses issued[2]	40	44	42	35	42±7	21±3
FPA total contribution (€/year)	2~~.~~,500,000	3~~.~~,430,000	280,000	600,000	650,000	980,000
Accessing fees per vessel (€ after 2003)	-	-	-	3,000	4,200	5,100
Annual fees from license (€)	40,000	44,000	42,000	105,000	176,400±29,400	107,100±15,300
Shipowner contributions per mt (€)	20	20	20	25	35	35
Reference catches per licence fee (mt)	50	50	50	120	120	146
Total allowable catches (mt)			-	8,000	10,000	8,000

[1]The number of licenses issued under 1987 FPAs included purse seine and longline vessels
[2]Number of purse seine fleet also includes other non-European vessels

3.2. Knowledge of small-scale tuna fishers

The largest tuna size recalled (in kilograms) by fishers ~~is shown in Figure 4, and~~ demonstrateds a declining ~~trend~~ rate of about 2.5% per year (Figure 4). Most of the fishers interviewed reported that the largest tuna they had ever seen had been observed between 5 and 10 years prior to ~~the reference years~~ 2017/2018.~~2017 to 2018, when the interviews were conducted.~~ When fisher responses were separated into two groups, those with up to 10 years of experience and those with more than 10 years of experience, the younger and less experienced fishers reported that the largest tuna they had ever caught or seen (average = 40 ~~kg~~kg) was caught around 2008, ~~10 years prior to the interview (i.e., in 2008),~~ whereas the older and more experienced fishers reported that the largest tuna they had ever caught or seen (60 to 75 ~~kg~~kg) was caught between 1975 and 1980. Given the modelling approach and the low number of samples at the beginning of the series, the declining rate seems to be more pronounced before 1995 (3.2%), followed by a flattening trend. . Despite that, the largest tunas mentioned by fishers were two individuals weighing 100 kg each that was observed in 2008 and 2017. Yet, the dispersion of the fisher's responses especially in the more recent years shows a poor adjustment of the data (Figure 4; r2 = 0.12).

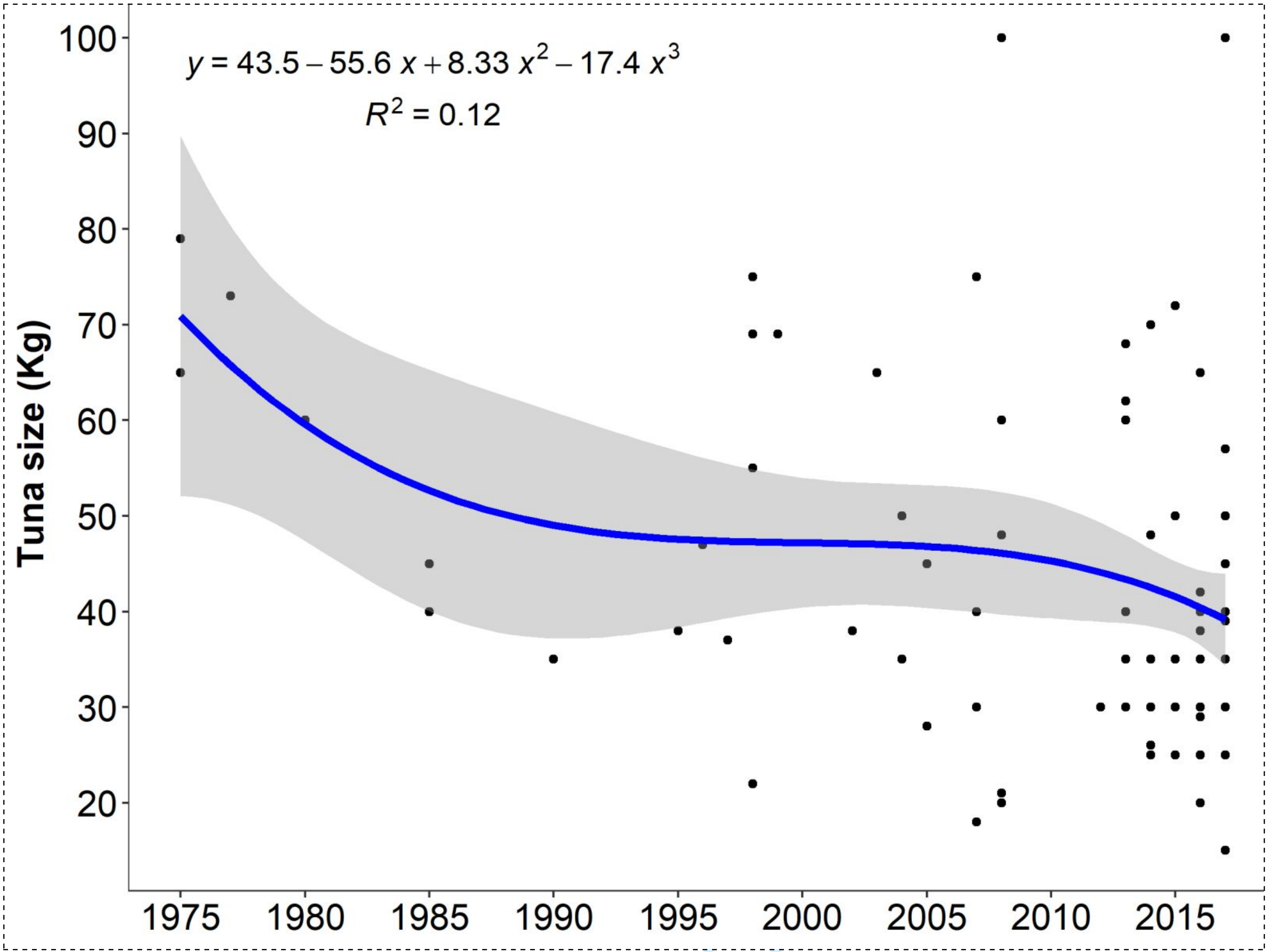

Figure 4 - Historical trend of the largest tuna ever recalled to have either been seen or caught by small-scale fishers.

~~Despite the overall declining trend, the largest tunas mentioned by fishers were two individuals weighing 100 kg each that had been caught in 2008 and 2017, respectively (Figure 4; $r^2 = 0.12$).~~

The seasonality of tuna species occurrence~~, according to fishers,~~ also varied according to the ~~research~~ region, according to fishers. ~~Fishers~~ They reported a higher occurrence of tropical tuna from late December to May in areas A and B (northern region), whereas in area C (southern region) species were reported to be mostly caught between late June and November (Appendix S2, Figure 2). ~~In fact, t~~ The seasonality of fishing seems to be especially marked for skipjack, which is rarely caught between June and November in region A, becomes slightly more reported during this same period in region B, and then is said to be predominantly caught in this season in Region C (Appendix S2, Figure 2). Both b~~B~~igeye and y~~Y~~ellowfin tuna are also absent between June and November in Region A, but present at similar rates, or even higher, in Regions B and C.

When fishers were asked about the average size (~~kg~~kg) of the tuna they normally catch, both b~~B~~igeye (most catches between 5 ~~Kg~~kg to 30 ~~Kg~~kg) and s~~S~~kipjack tunas (between 1 and 7 ~~kg~~kg) showed a positively skewed distribution, whereas y~~Y~~ellowfin tuna (between 5 ~~Kg~~kg to 30 ~~Kg~~kg) followed a normal distribution (Appendix S2, Figure S3). Fishers reported that they mostly target ~~S~~skipjack, which, according to 83% of the fishers interviewed, is the main species occurring in the area (Table 2). The occurrence of b~~B~~igeye and y~~Y~~ellowfin tuna~~, which were said to be~~ usually caught as juveniles, were reported by 53% and 60% of the fishers, respectively (Table 2).

The average size reported for ~~S~~skipjack in region A was larger than the average size reported in the other regions (A x B: F=4.01, p-values= 0.0003; A x C: F= 2.84, p-value=0.0133) (Table 2). No difference was detected between regions B and C (F = 0.7077; p-value = 0.3527). For b~~B~~igeye and y~~Y~~ellowfin tuna the average size did not vary across regions: b~~B~~igeye (A x B: F=1.45, p-values=0.2932; A x C: F= 0.80, p-value=0.7757; B x C: F=0.45, p-value=0.1117), and y~~Y~~ellowfin (~~-~~A x B: F=1.95, p-values=0.2174; A x C: F= 0.77, p-value=0.5993; B x C: F=0.40, p-value=0.07305).

Over the last 5 to 10 years prior to 2017-2018, 65% (*n=101*) of the fishers interviewed perceived a decline in tuna occurrence. This was especially marked in region C, where 88% of the fishers interviewed claimed to have noticed this decline, in~~. By~~ contrast with~~, only~~ 50% of the fishers ~~interviewed~~ in the other two regions ~~claimed to have noticed this decline~~ (Table 2). Despite the reported declines, most interviewees in region A (64%) still considered it easy to catch tuna, according to their fishing experience, gear used, and season. By contrast, in regions B and C, almost 63% of the fishers suggested that it was difficult to catch tuna due to either a lack of technologies or scarcity of tuna (Table 2). The vast majority of fishers (~85%) claimed that tunas are mostly caught at sunrise and sunset (Table 2).

In general, fishers did not perceive much overlap in fishing grounds between industrial purse seiners and their own activity, although the situation is less clear in Region C (A= 76%, B = 94%, C = 58%), which suggests that there are some eventual overlapping grounds (Table 2). The interviewed fishers have never seen FADs lost from industrial seiners, nor do they use FADs to attract fish (Table 2).

Table 2 - Summary of the interview data related to changes in tuna catches, and interactions with industrial fleets. A, B and C indicate regions of clustered sampled villages. SKJ-skipjack, BET- bigeye tuna, YFT- yellowfin tuna, FAD-fishing aggregating device. Percentage values in brackets in rows of boat size correspond to the number of respondents.

Item	Category	Sampling regions			Overall
		A (=33)	B (n=35)	C (n=33)	(n=101)
Tuna species average size (kg) (% in brackets referrers to the number of fishers who reported each species per region)	SKJ	7.64 ±4.39 (76%)	4.15 ±2.19 (97%)	6.12 ±2.60 (76%)	5.77±3.41 (83%)
	BET	18.07 ±7.04 (42%)	16.19 ±4.73 (60%)	19.42 ±6.67 (56%)	17.81±6.14 (53%)
	YFT	22.82 ±8.36 (52%)	19.27 ±5.99 (42%)	16.82 ±9.51 (85%)	19.13±8.68 (60%)
Number of fishers 5 years before 2017/2018 (%)	Increased	55	63	70	62
	Did not change	33	29	6	23
	Decreased	12	8	24	15
Perceived trend of tuna abundance over the last 5-10 years before 2017 (%)	Increased	45	46	12	35
	Decreased	55	54	88	65
Has it been easy to catch tuna over the last 2 years (%)	Yes	64	37	36	54
	No	36	63	64	46
Best period of the day to catch tuna (%)	Sunrise and Sunset	85	86	85	85
	No difference	15	14	15	15
Have previously seen industrial vessels in their fishing sites (%)?	Yes	24	6	42	24
	No	76	94	58	76
Have previously seen or used FADs (%)?	No	100	100	100	100
Average Fishing Time	Hours per day	6.70±3.19	6.77±3.28	5.94±2.41	6.48±3.01
	Day per month	19±3	20±3	15±4	18±4
Boat size (m)	Engine	4-11 (33%)	8-12 (57%)	3.5-10 (79%)	3.5-12 (57%)
	Sail and rowing	2 -8.5 (67%)	3-10 (43%)	3-6 m (21%)	2.5 -11 (44%)

3.3 **Socioeconomic aspects of small-scale tuna fisheries**

The three regions differed in the proportion of gear~~s~~ types used (Table 3). In region A, hand lines predominate (45.5% vss~~versus~~ 30.3% small seine vs ~~and~~ 24.2% gillnets), whereas in Region B small seines are used by the majority of fishers (57% vs~~versus~~ 29% hand line vs~~and~~ 14% gillnets), and in Region C, in the south, only hand lines are used~~interviewed esors~~ in visited villages in region C~~.~~

The distribution of fishing gear~~s~~ and how they are used across regions also affects the number of people employed in each place. For example, the crew sizes of boats that operate gillnets in Region A range from 4 to 20 fishers per vessel, compared to 6 to 17 people per vessel in Region B, where the smaller the boat, the smaller the crew size. The average daily working time for gillnet fishers is ~11 hours in both regions A and B, and approximately 17 to 19 average days per month. Therefore, the monthly average working loads were estimated at 14.2 ±0.3 and 15.1 ±0.2 FTE jobs for areas A and B, respectively (Table 3).

With respect to handline fishers, the average crew size is 3 ± 2 and 5 ± 2, and ranges from 1-7 in regions A and C, while in the villages visited in region B, fishers worked alone. The average working time for handline fishers was around 10 hours per day for all three of the visited areas. Handline fishers declared an average of 21 fishing days per month in areas A and B, while in region C the declared average was about 15±4 days per month. Hence, the monthly workloads for handline fishers were set to 3.89 ± 0.7, 1.3 ± 0.3, and 5.1 ± 4.99 FTE jobs in the villages in areas A, B, and C, respectively (Table 3). Compared to the normal working hours of the average worker in the country, the monthly working hours are relatively higher in areas A and C, being~~and,~~ close to the average workload in area B, because in area B fishers mostly work alone.

On average, small seines provide more jobs than the other gear~~s~~ (26 ± 6 and 23 ± 9 fishers in region A and B, respectively). The working load for seiners is about 12 hours per day in villages in region A, and 11 hours in villages in region B, with working days set to an average of 18±3 and 20 ±3 in region A and B, respectively.

Hence, compared to a full-time employee, the monthly workload was found to be 34.4 ±12.3 FTE jobs in region A, and 32.9 ±22.1 FTE in region B (Table 3). This is the highest workload among all previously described fisher groups, and >30 FTE times higher than the average monthly hours of an average worker.

In all the fishing villages evaluated, most fishers (>50%) have to invest time and money to maintain their fishing equipment, while less than 23% of fishers interviewed, i.e., those working for a patron, do not know who funds their fishing. Few fishers have been beneficiaries of any type of credit (e.g.: government subsidies, loans from NGO or banks) , although in region C~~region C this value can reach~~ 30.3% of the fishers had access to some sort of credit (Table 3).

Gillnet fishers are remunerated based on a shared income team-fisher system (type *ii*) (Table 3). Overall, gillnet fishers in region A make 1,5 times more money than fishers in region B. Boat owners were only accessed in region B, and were found to make more than twice the amount that fishers make in the high season (December - May), and 82% of the average fisher income in the low season (June - November) (Table 3).

Small purse seiners are also arranged in a team-fishers system (type *ii*) and share fishing revenues (Table 3). In region A, boat owners earn, on average, about 1.5 times more than the fishers working for them. In region B a boat owner makes more than 2 times ~~what~~ than fishers make in the high season and 89% of what fishers make in the low season. When regions are compared, boat owners from area A make 84% of the average income of boat owners in area B in the high season, and similar incomes in low season. The incomes of fishers, by contrast, were similar between regions A and B in the high season. In the low season, fishers from region A earn an average of 76% of what fishers in region B earn (Table 3).

Hand line fishers~~Hand line fishers are organized in three different income systems (Table 3). Fisher~~ who are boat owners and patrons were only assessed ~~accessed~~ in region C and were found to make about 3 times more money in the high season than in the low season. Regardless of the season, patrons make almost twice the amount earned by fishers who are boat-owners. In region A, independent fishers make 29% of the average crew fisher's income in the low season, and 46% in the high season, respectively (Table 3). Independent fishers in region A were found to make more than twice that of independent fishers in region B in the high season, and three times as much in the low season, respectively. Crew-member ~~, whereas overall crew-member~~ fishers in region C were found to make about 60% of the average fisher's income in region A (Table 3).

Table 3- Summary of the socioeconomic aspects of small-scale tuna fisheries in Mozambique. A, B and C are the sampling village regions, and *n* is the sample size. FTE- full time equivalent jobs. i, ii, and iii indicates the types of revenue sharing: boat-owner (i) - fishers are also boat owners who pay for the costs and retain all the profits; team-fishers (ii)- 50% of the income for the patron, who is also a fisher, and the remaining is divided equally among the crew; patron (iii)-60% of the revenue is shared among the crew and 40% goes for the patron, who is not part of the crew. The % presented in brackets under the variable species prices corresponds to fishers who have been catching each species in the region. Incomes and prices were converted to euros and the reference year is the sampled year 2017 (https://ec.europa.eu/budget/graphs/inforeuro.html) as follows: 1 MZN (Mozambican currency) was equivalent to €0.0140025. December - May is the high fishing season, and June - November is the low fishing season.

Item	**Category**	**Sampled fishing villages, clustered by region**		
		A (n=33)	**B (n=35)**	**C (n=33)**
Funding sources for fishing (%)	Credit	9.09	22.86	30.30
	Self-funded	75.76	54.29	60.61
	Unknown	15.15	22.86	9.09
Nº of interviewees	Gillnet	9	5	No fisher found in visited villages
Crew size - gillnets		12 ± 6	11 ± 4	
Daily working hours		11.38 ± 2.91	11.2 ± 1.47	
Fishing days		17 ± 2	19 ± 4	
FTE per month		14.20 ± 0.27	15.05 ± 0.16	
Forms of income sharing		ii	ii	
% Respondents on gillnets		24.24	14	
Boat-owner (Dec-May) €		-	793.48 ± 462.06	
Boat-owner (Jun -Nov) €		-	74.68 ± 40.15	
Fisher (Dec-May) €		371.07 ± 299.58	245.04 ± 35.01	
Fisher (Jun -Nov) €		120.77 ± 119.62	91.02 ± 21.00	
Boat size (meters)		5 - 10	4 - 7	
Nº of interviewees	Handline	14	10	33
Crew size - handline		3 ± 2	1 ± 0	5 ± 2
Daily working hours		10.36 ± 3.67	10 ± 2.61	10.88 ± 5.27
Fishing days		20 ± 3	21 ± 2	15 ± 4
FTE per month		3.89 ± 0.02	1.30 ± 0.27	5.10 ± 4.87
% Respondents on handlines		45.45	29	100
Forms of income sharing		ii and iii	ii and iii	i, ii and iii
Boat-owner (Dec-May) €		-	-	380.61 ± 239.71
Boat-owner (Jun -Nov) €		-	-	122.84 ± 79.40
Independent fisher (Dec-May) €		257.30 ± 266.50	106.57 ± 16.04	-

Independent fisher (Jun -Nov) €		87.52 ± 109.25	25.67 ± 11.43	-
Crew fisher (Dec-May) €		555.43 ± 431.79	-	346.93 ± 400.10
Crew fisher (Jun -Nov) €		303.39 ± 277.08	-	178.50 ± 244.70
Patron (Dec-May) €		-	-	644.12 ± 491.88
Patron (Jun -Nov) €		-	-	208.64 ± 117.19
Boat size (meters)		3 - 6	2.5 - 5	3 - 7
Nº of interviewee		10	20	No fisher found in visited villages for the sampling period
Crew size – purse seine		26 ± 6	23 ± 9	
Daily working hours		12 ± 4.15	11 ± 4.32	
Fishing days		18 ± 3	20 ± 3	
FTE per month		34.44 ±12.34	32.93 ±22.14	
% Respondents on purse seine	Small purse seine	30.30	57	
Forms of income sharing		ii	ii	
Boat-owner (Dec-May) €		455.08 ± 282.23	542.87 ± 325.53	
Boat-owner (Jun - Nov) €		117.27 ± 93.39	95.32 ± 82.82	
Fisher (Dec-May) €		280.08 ± 70.01	252.05 ± 224.74	
Fisher (Jun -Nov) €		80.51 ± 59.51	106.42 ± 123.22	
Boat size (meters)		8 -11	8 - 12	
Range of net income (€)	Dec-May	42.01 - 1,680.30	42.01 ± 1,400.25	42.00 ± 2,800.50
	Jun-Nov	14.00 - 840.15	14.00 ± 280.05	14.00 ± 1,050.19
Species price (€)	BET	1.24 ± 0.36 (42%)	1.16 ±0.33 (60%)	2.13 ± 0.59 (67%)
	SKJ	0.92 ± 0.29 (61%)	0.83 ±0.33 (100%)	1.84 ± 0.60 (85%)
	YFT	1.34 ± 0.40 (48%)	1.19 ± 0.32 (42%)	2.13 ± 0.43 (86%)
Tuna destination (%)	Market	100	100	49
Fisher satisfaction (%)	Satisfied	63.64	68.57	85.85
	Unsatisfied	9.09	11.43	15.15
	No comment	27.27	22.86	0

4. Discussion

Although the record of fisheries statistics in Mozambique have been improving in the last two decades (Afonso et al., 2017) the country still struggles to offer high-resolution temporal and spatial information by species caught in the Mozambique EEZ. This is why an assessment of industrial tuna fisheries in Mozambique requires the use of international data, as done here, together with interviews with small-scale fishers. Hence, the implementation of the provisions included in the FPAs, where fisheries statistics, regional offices, observers, etc. are requested to complement the inconsistence or scarcity of data. However, relying on fishers' knowledge is a relatively reliable strategies to gather information data and estimate changes on fisheries when official statistics are inconsistent or not well documented (Huntington, 2000; Damasio et al., 2015).

Foreign purse seine tuna fleets, especially European fleets, have been fishing in Mozambican waters since the 1980s. Between that time and the 2000s, industrial purse seine tuna catches increased at a ~~fast~~rapid rate, ~~. This growth rate was influenced~~as indicated by a growing number of licences issued to European purse seine vessels, mainly from France and Spain (EC, 1987; Parks, 1991). These vessels ~~, which~~ were equipped with advanced fishing technologies (Fonteneau et al., 2013; Lopez et al., 2014; Lopez and Scott, 2014; Torres-Irineo et al., 2014) that enabled an increased fishing effort ~~(Appendix S2, Figure 4).~~ . After the 2000s~~,~~ catches started to decline, in part because a number of fleets exited ~~exiting~~ the fisheries industry in response to high levels of piracy observed in the WIO (Chassot et al., 2012; Pillai, 2012). As a result, after the 2000s~~,~~ fishing hours and catches per unit effort also declined ~~(Appendix S2, Figure 4).~~ . For example, in Mozambique about 51 purse seine vessels applied for licenses in 2007, whereas in 2014 this number dropped to 22 (Chacate and Mutombe, 2018). Despite regional and international efforts to decrease ~~secure the level of~~ piracy in the Mozambique Channel (Pillai, 2012; Bergeron, 2014), ~~to date~~ the FPAs with the EU have not been renewed since 2014. ~~, which expired at the end of 2014, have not been renewed~~ (Chassot et al., 2019). In addition to piracy, the FPA negotiations have been affected by a lack of agreement on transparency clauses that would allow Mozambique to improve its monitoring of catches by EU vessels ~~in its waters~~ (Davies and Markides, 2019). ~~Apparently t~~The government of Mozambique continues to negotiate sustainable (i.e., ecologically and socioeconomically sustainable) FPAs with foreign fleets, although the number of purse seiners fishing in domestic waters dropped to eight~~8~~ in 2015 and to four~~4~~ in 2018 (Chacate and Mutombene, 2019). The lower number of industrial boats targeting tuna may be~~, however, is perhaps~~ not the only reason why catches have declined. Factors such as overfishing (Campling, 2012) and changes in oceanographic conditions may have also played a role. ~~Climate change and a~~Increased ~~larming~~ oceanic warming (Popova et al., 2016) may induce climate change with ~~have~~ implications on the seasonal migration and aggregation of tropical tuna ~~I~~in the Mozambique Channel, ~~F~~for example, species are predicted to shift their aggregation toward southern and temperate waters by the end of the century (Dueri et al., 2014; Marsac, 2017) or displaced elsewhere and moving to deep water in the ocean (Monllor-Hurtado et al., 2017). These changes ~~of target species(Dueri et al., 2014)(Marsac, 2017), which~~ ultimately may have implications on fleet behaviour and the strategies they adopt to keep fishing profitable. On the other hand, even if stocks have declined, the CPUE has not shown clear signs of decrease yet. In both sources of purse-seine data used here, the CPUE has been relatively stable since the beginning of the 1990s, with a slight increasing trend in the last two to three years of the time series, possibly a result of fewer boats fishing Mozambican waters and/or improved technology~~.~~

Although they are not affected by piracy, small-scale fishers also noticed a decline in tuna catches and perceived a decrease in the size of individual tunas (assessed here by the recollection of the largest tuna ever caught). However,~~Although~~ small-scale and industrial fishers, in general, do not compete over the same fishing grounds (there is likely some competition happening in Region C – surprisingly the area where purse seine activity is lowest),~~–~~but they do compete over the same stocks~~.~~ given that there is a single stock for each tropical tuna species in the Indian Ocean (IOTC, 2021. Thus, if there were a real decrease in the tuna stocks exploited by foreign fleets, it would be expected to cause a similar ~~natural to also observe this~~ decline among local small-scale fishers closer to the coast (Hampton, 1991; Kleiber, 1991; Leroy et al., 2016). The fact that small-scale fishers noticed such a decline reinforces the hypothesis that the decline in industrial fisheries is not entirely due to fear of piracy. Indeed, recent IOTC assessments of y~~Y~~ellowfin tuna have shown that this species is overfished, and that overfishing continues to occur (IOTC, 2018; IOTC, 2021) ~~(www.iotc.org~~). Other species, such as ~~Skipjack and~~ b~~B~~igeye tuna are, subjected to overfishing, although the stock is not overfished. ~~seem to be in better shape,~~ Skipjack~~-s~~ seems to be in better conditions, but the probability that the species ~~Skipjack~~ is either overfished or that overfishing is occurring is close to 50% ~~(www.iotc.org)~~ (IOTC, 2018; IOTC, 2021).

~~Overall, tuna stocks are harvested with a variety of gears (e.g., longlines, purse seines, pole -and-line, gillnets and handlines), both in the high seas (>12 nm) and in coastal waters (Lecomte et al., 2017; Mutombene et al., 2017; Chacate and Mutombe, 2018; Chassot et al., 2019).~~ Additionally, fishers within the same category compete with one another, as is the case for small-scale fishers within a given region who compete to ensure their income and livelihoods. Nevertheless, the lack of data (e.g., tagging, species size and weight composition information) makes it difficult to elucidate and quantify the magnitude of interactions between fishing sectors and among fishers in the same sector (Kleiber, 1991; Leroy et al., 2016).

It is also worth ~~highlighting~~ noting that, despite the decreasing maximum weight observed by fishers with respect to the largest fish ever caught, a significant portion of small-scale fishers (<45%) consider that tuna populations have not been declining and that their decreasing catches are a consequence of limited technology. According to these fishers, if they had access to better gear, their catches would improve. ~~Basically, these fishers~~They would like to increase their effort and/or efficiency to make up for their growing losses, which is a strategy that many fisheries around the world turn to (Damasio et al., 2016). This strategy, often stimulated by governmental subsidies, is not only just a short-term solution, but also tends to worsen the stock situation (Sumaila et al., 2010; Sumaila et al., 2016). This misunderstanding of the causes behind stock depletion and the lack of capacity to find alternative resources to make up for decreasing incomes (e.g., access to better markets) are related to multiple factors, including the literacy barrier. Cognitive limitations due to poor or limited education can hinder fishers' access to financial credits, economic diversification, and ~~access to~~ market information that would allow them to negotiate better contracts for fish products ~~with quality standards~~ (Fatunla, 1997; McGoodwin, 2001; Maddox, 2007).

Although the EU, NEIPS, and regional purse seines fleets have brought some economic benefits to Mozambique, mostly in the form of fees paid to the government, they had limited impacts on ~~different~~ other socioeconomic levels. For example, between 2006 and 2017, the average annual contribution from foreign industrial tuna fleets to the national fisheries sectors was about 18% of €2.95±1.02 million, gathered from overall fisheries licencing fees (Afonso et al., 2017). ~~Other~~ Many African and developing coastal countries have used fishing agreements to strengthen their governance, by improving the sustainability and profitability of their accords with the developed world (Barclay and Cartwright, 2007; Mailu et al., 2015). Countries such as the Seychelles, Mauritius, and Madagascar have, for instance, demanded national prioritization of port transshipments ~~and~~ tuna and by-catches species landings, employment of national fishers, establishment of fish processing units, and the development of a national industrial tuna fleet (Lecomte et al., 2017b). Canneries alone, which were established to process tuna purse seine catches, generated about €5.6, €56.32, and €76.05 million for Madagascar, Seychelles and Mauritius in 2016, respectively (Lecomte et al., 2017b), whereas Mozambique, in that same year made about €0.65 million : only ~~(93% from tuna licensing fees), about~~ 7% of which was from tuna added value products, and the remaining from licensing fees (Afonso et al., 2017).

In ~~port~~ states where tuna is transhipped there can be multiple benefits, including ~~extending from social (e.g.,~~ jobs and improved food supply~~) to economic benefits (profits), along the fisheries value chain~~, as observed, for example, in Tuvalu, Salomon Islands, and Marshall Island (Barclay and Cartwright, 2007; James et al., 2018), and some WIO region countries (e.g., Maldives, Seychelles, Mauritius, Madagascar, etc.) (Lecomte et al., 2017). A decree (nº 74/2013) published in 2013 by the Mozambican government (Ministers-Council, 2017) ~~is~~has yet to be enforced, but it could potentially improve local socioeconomic conditions by demanding that transhipments, landings, and fish processing take place in the country. This decree is also expected to enforce the ~~demand~~ requirements for scientific observers onboard, data collection systems, and the employment of Mozambican citizens on international boats; aspects that were required, but not fulfilled, in previous FPAs.

If well implemented, the benefits of agreements could partially offset ~~some of~~ the current loss of FTE jobs (e.g., one or two weeks without fishing per month) among small-scale fishers due to adverse oceanic and coastal environmental conditions for fishing~~, and~~ ~~improve~~ while improving statistical data. Currently, Mozambique has been following the path of other developing tropical small-scale fisheries (Fatunla, 1997; Pauly, 1997), whereby its catches are landed out of urban centres and markets and without the use of official national ports. If industrial tuna fisheries were to tranship and land their fish products in national ports, these additional jobs could be occupied by some of the family members of fishers without interfering ~~much~~ in the dynamics of SSF villages. This already happens, for example, with industrial shrimp fisheries (Santos, 2007). Similar positive socioeconomic interactions have also been noted between industrial tuna fleets and SSFs in some of the Pacific Islands, specifically in Tuvalu (James et al., 2018).

~~Furthermore, besides the socioeconomic impacts,~~ FPAs between distant water nations and other African nations have also been criticized for promoting potential overfishing (Nagel and Gray, 2012; Augustave, 2018), and for either a lack or inconsistent fisheries data collection and reporting to IOTC for stock assessment and management advice~~, which adds significant uncertainty to the degree of stock exploitation~~ (Otterlei, 2011; IOTC, 2018). ~~However, the IOTC's most recent assessments of skipjack and bigeye tuna stocks indicated that these species are in a fairly good condition, although important concerns were raised about yellowfin tuna, which was determined to be overfished, with overfishing still occurring (Lecomte et al., 2017a; IOTC, 2018; Davies and Markides, 2019).~~ . Proposals to adopt sustainable fishing partnership agreements (SFPA) have been discussed in the literature, and they include the protocols, provisions and recommendations by the IOTC (e.g., IOTC, Resolutions: 17/01; 18/01 and 19/01) on tuna and tuna-like species (Augustave, 2018; Davies and Markides, 2019). Despite the fact that several coastal states have tried to follow the IOTC recommendations, the SFPAs have been hampered by the difficulty of competing with subsidized tuna fleets (Grynberg, 2003; Arthur et al., 2019; Davies and Markides, 2019). For example, ~~fisheries~~ subsidies maintain the overfishing of yellowfin tuna in the WIO region, which includes the Mozambique Channel, which would be unprofitable otherwise (Arthur et al., 2019). Mozambique is one of the developing states where tuna fishing is carried out by subsidized foreign industrial fleets with FPAs access (Grynberg, 2003; Arthur et al., 2019), whereas local SSFs targeting tropical tuna are subsidized by microcredits provided by the national government (Benkenstein, 2013).

The socioecological interactions observed in this study, in locations where industrial fleets and SSFs compete for ~~over~~ the same stocks, have been reported elsewhere (Kleiber, 1991; Hampton, 1991). In Mozambique, specifically, there has been an attempt to regulate this competition by geographically separating the activities (as per the national fisheries law nº 23/2013) and by limiting SSFs to up to 12 nm offshore, where the industrial fisheries jurisdiction begins. Industrial purse seine fleets seem to monitor and manage their FADs efficiently (Soto et al., 2016)~~,~~ by controlling ~~them from drifting toward SSF~~fishing areas and minimizing the possibility of direct interactions and impacts with SSFs. However, ~~the main competition appears to be in the fact that~~ the same stocks are being exploited by both fleets, especially ~~. The three species of tropical tuna caught in the high seas by industrial fleets were also reported to be caught in coastal areas by small-scale fishers, i.e., SKJ (60% of mentions), BET and YFT (>25%). These species have been caught by SSFs over the years, but~~ in the high SSF fishing season ~~(December - May) in Mozambique there is overlap with the fishing seasons of industrial purse seine fleets in area~~ (Campling, 2012; Kaplan et al., 2014; Obura et al., 2018). ~~With respect to Mozambican tuna fisheries, the competition between industrial purse seiners and SSFs probably peaks in the high season, when fishing becomes more profitable.~~ In the low season, when there is no industrial fishing in the region (Campling, 2012; Obura et al., 2018), competition over resources probably occurs among SSFs. In developing countries, it is common for SSFs to target the resources ~~that offer the best~~ gratest abundance (easier to catch) and profit ~~compromise~~ to maximize income and livelihoods (McGoodwin, 2001; Tietze, 2016). Although it is seasonal, SSFs ~~fisheries~~ income in the high season was comparable to the income paid to staff working in the public fisheries sector (not including ~~the~~ high paid managerial jobs) for the period 2017-2019 (MEF et al., 2017; MEF et al., 2019). ~~Hence, tuna fish~~ Tuna continues to be a profitable commodity for small-scale fishers and, consequently, tuna fishing continues to attract newcomers (as perceived by the small-scale fishers interviewed). ~~, which~~ This leads to increases in the fishing effort (Gordon, 1954; Panayotou, 1982; Pitcher and Lam, 2015) and –intensifies competition (Campling, 2012).

Socially, small-scale purse seine fleets provide more jobs in Mozambique (61% of total fishing-related jobs) than gillnet and handline fishing. The regional distribution of fishing gear i.e., small purse seine and gillnets in north (region A and B) could be related to the traditional and cultural fishing system acquired from ancients or experience transmitted through generations in the communities (McGoodwin, 2001). With a total of 954 jobs generated by SSFs targeting tuna in the three regions analysed, it is estimated that Mozambique requires ~160 small-scale fishers to land a tonne of tuna. As a comparison, the Maldives requires 180 fishers, Iran 956 fishers, and the EU industrial purse seines in the WIO region, only six people (Lecomte et al., 2017a; Lecomte et al., 2017b). These figures do not include the extensive value chain of small-scale fishers, with an intricate web of middlemen that in many cases distribute the fish from the villages to the main cities and neighbouring countries. ~~Most of the the fleet sthe are small purse-seine or gillnet , whohave acquiredsignificant geesAlso, tand ed'predominantly selecting eesdiversity of led to favour~~

~~The findings of this study contribute to a better understanding of the~~ ecological, economic and social~~three pillars of tuna fisheries sustainability in Mozambique, i.e., ecological, economic and social (Asche et al., 2018). In terms of ecological sustainability,~~ there is evidence~~the findings of this study suggest that the local catches of tropical tuna in Mozambique have been declining over the last 10 years. Although part of this decline can be attributed to piracy, which has forced some fleets out of the region, real stock declines cannot be dismissed, especially considering that small-scale fishers, who are not subject to piracy, have also noticed~~ ~~it~~this decline. ~~Yet~~While the causes of the decline are not clear, as a precautionary approach, improved

~~management measures should be considered at both local and international levels, along with improved fisheries data collection and investments in scientific research. Economically and socially, there is still room to make fishing agreements more beneficial to the Mozambican population, by ensuring that both transhipments and processing occur domestically, thereby generating more jobs, ensuring that part of the profits and revenues circulate within the country, and enforcing some accountability (POSEIDON et al., 2014; Lecomte et al., 2017b; James et al., 2018). Furthermore, the government should actively enforce the non-use of the reserved nearshore fishing grounds (<12 nm) by industrial fisheries to decrease potential future conflicts between small-scale and industrial fisheries. Moreover, the fish harvested by small-scale fishers should also be counted and incorporated into official national statistics (Kleiber, 1991; Leroy et al., 2016). Finally, economic diversification and improved the literacy rates among small-scale fishers should be promoted in order to better prepare them for future resource failures, whether it be caused by overfishing, climate change or any other factor (Fatunla, 1997; FAO, 2006; Maddox, 2007).~~

5. Conclusions

The findings of this study contribute to a better understanding of the ecological, economic and social pillars of tuna fisheries sustainability in Mozambique. In terms of ecological sustainability, there is evidence that the local catches of tropical tuna in Mozambique have been declining over the last 10 years. Although part of this decline can be attributed to piracy, which has forced some fleets out of the region, real stock declines cannot be dismissed, especially considering that small-scale fishers, who are not subject to piracy, have also reported it. As a precautionary approach, improved management measures should be considered at both local and international levels, along with improved fisheries data collection and support of scientific research. Economically and socially, there is room to make fishing agreements more beneficial to the Mozambican population, by ensuring that both transhipments and processing occur domestically. This would generate more jobs and ensure that part of the profits and revenues circulate within the country and improve accountability. Efforts should also be made to actively enforce the exclusion of industrial fisheries from the reserved nearshore fishing grounds (<12 nm) to decrease potential future conflicts. In addition, the fish harvested by small-scale fishers should be incorporated into official national statistics.

This study also suggests that ~~nominal tuna catches have been declining over time in Mozambique, regardless of whether the fish are caught by industrial or small-scale fishers. C~~competitive interactions among industrial fleets and SSFs over ~~valuable commercial~~ tuna species~~, such as~~ skipjack, yellowfin and bigeye~~*K. pelamis* (SKJ), *T. albacore* (YFT) and *T. obesus* (BET),~~ have possibly been contributing to stock ~~this~~ decline, given that the same stocks are being harvested in different regions of the WIO ~~(coastal and high seas)~~ and by all types of gear. Better policies and a stronger governance that facilitates and promotes landings, transhipments, and tuna and by-catch processing in Mozambique will likely improve the social and economic outcomes of both SSFs and the Mozambique fishing. Future agreements should be socially and ecologically fair and supported by sound management advice on the sustainability of exploitation rates. Economic diversification and improved literacy rates among small-scale fishers should be promoted to better prepare them for possible resource failures, whether it be caused by overfishing, climate change or any other factor. ~~The fact that there may be some interaction between industrial fisheries and SSFs, particularly in some regions (e.g.: villages in Inhambane and Maputo provinces),~~ which may ~~contributes to the potential consequences of declining fish stocks on less powerful actors, i.e., small-scale fishers. Thus, it is important to enforce the already existing legal separation of extraction areas between small-scale and industrial fisheries. The northern coast of Mozambique was also observed to be more directly dependent on tuna fishing, as observed by both the larger number of fishers involved in the extractive segment and of other people working along the fishing value chain. Better policies and a stronger governance that facilitates and promotes landings, transhipments, and tuna and by-catch processing in Mozambique will likely improve the social and economic outcomes of both SSFs and the industrial fishing industry in the country.~~ Avoiding~~It is important to avoid~~ ~~tuna overexploitation in Mozambican national waters while also avoiding the social exploitation of the country by unfair~~

~~agreements is a necessary step. Future agreements should be socially and ecologically fair and supported by sound management advice on the sustainability of exploitation rates.~~ Although preliminary, this is the first study that adopts an integrative approach to understanding the effects of having economically important stocks shared by distinct types of fisheries, especially on the more vulnerable link of the chain; local small-scales fishers.

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Annex B - Figures

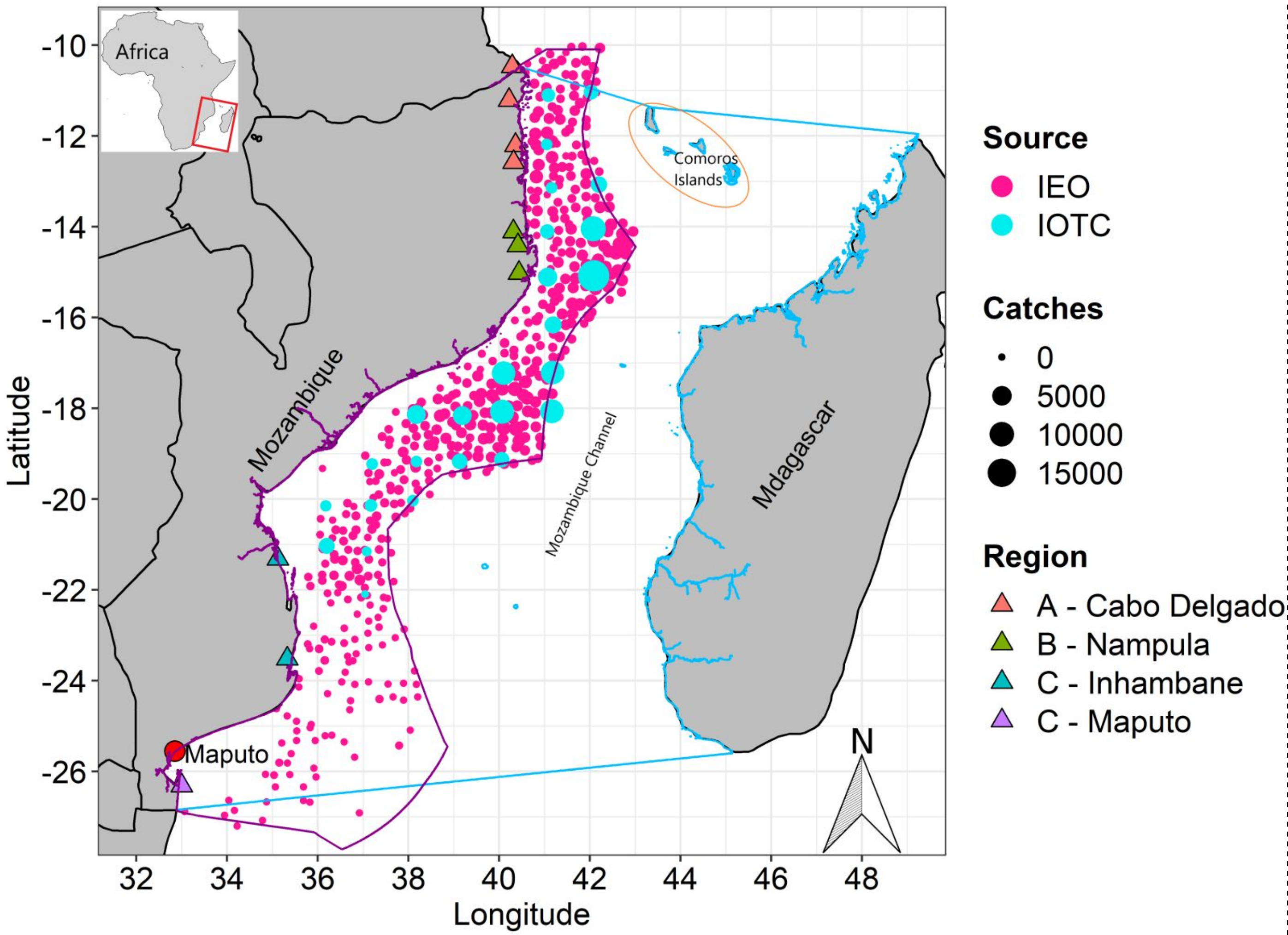

Figure 1. Map of the study area showing the distribution of tropical tuna (circles) catches, in tonnes by industrial purse seine fisheries, in the Mozambique Economic Exclusive Zone (delimited by the magenta line), as part of the Mozambique Channel (area delimited by the deep sky-blue line) for the period 1983 to 2014. Data were spatially aggregated as the sum of a 1/4º grid cell. The triangles mark the coastal villages in each region (A, B and C) where interviews with small-scale fishers and fishing authorities took place. Catches correspond to the tropical tuna species (SKJ - *Katsuwonus pelamis*, YFT- *Thunnus albacares*, and BET - *Thunnus obesus*). IEO logbook data refers to purse seine Spanish fleet fishing. IOTC (purse seine fleets from the EU, the Seychelles, and Mauritius, among others) for commercial data was gathered from all purse seine fleets that fished in Mozambican waters during study period. Shapefiles for Mozambique EEZ and the Mozambique Channel were accessed from https://www.marineregions.org. The red dot in the southern coast of Mozambique indicates Maputo, the country's capital.

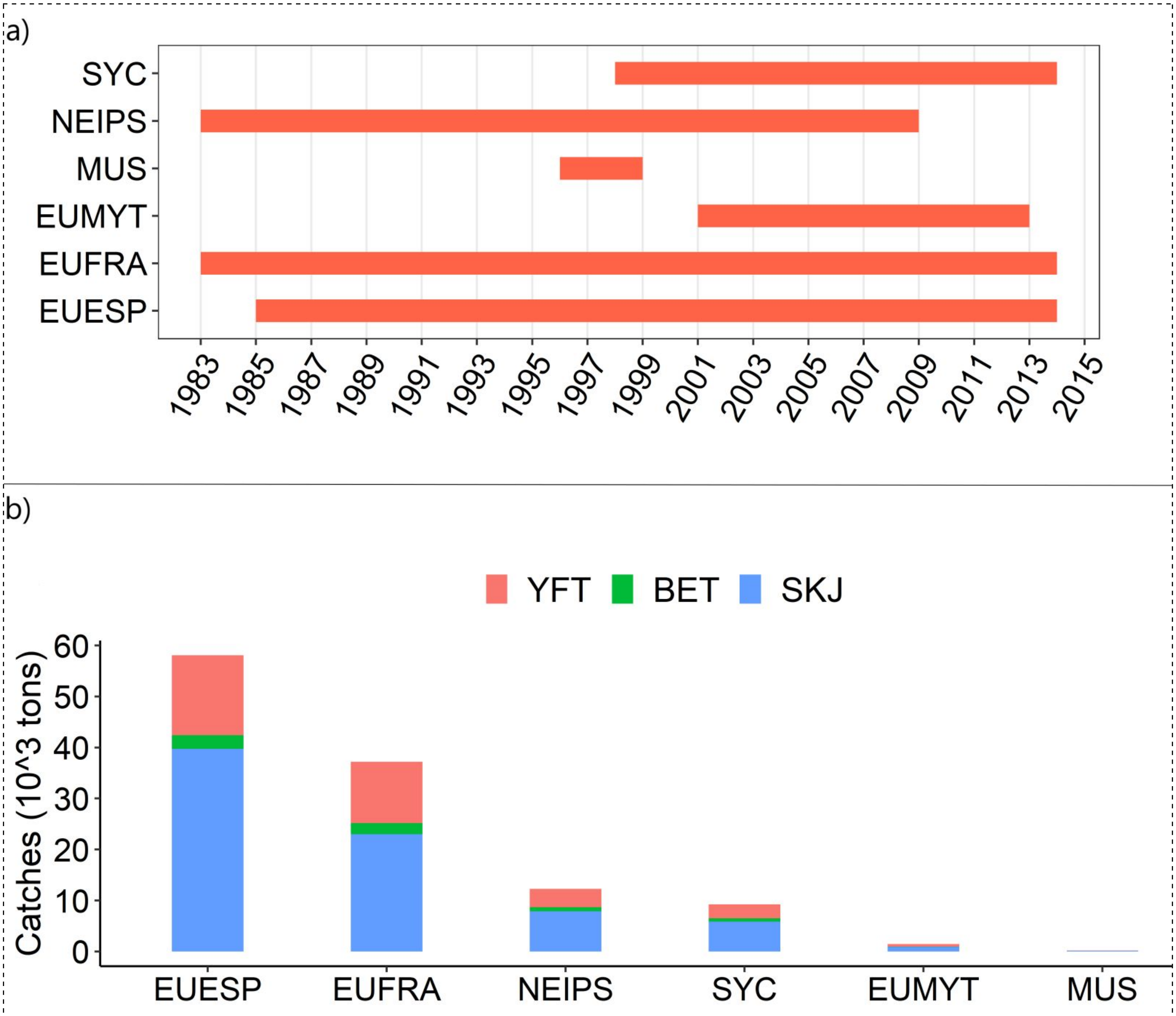

Figure 2. Timeline of purse seine fleets operating in the Mozambican EEZ and targeting tropical tuna between 1983 and 2014 (a), and their respective total catches over time (b). All fleets are international: EUESP - Spanish, EUFRA - French, NEIPS - Other fleets, SYC -Seychelles, EUMYT- Mayotte Island French territory, and MUS - Mauritius fleets. BET- bigeye tuna, SKJ - skipjack, and YFT-yellowfin tuna. There are no records of Mozambican purse seine fleets operating in the region.

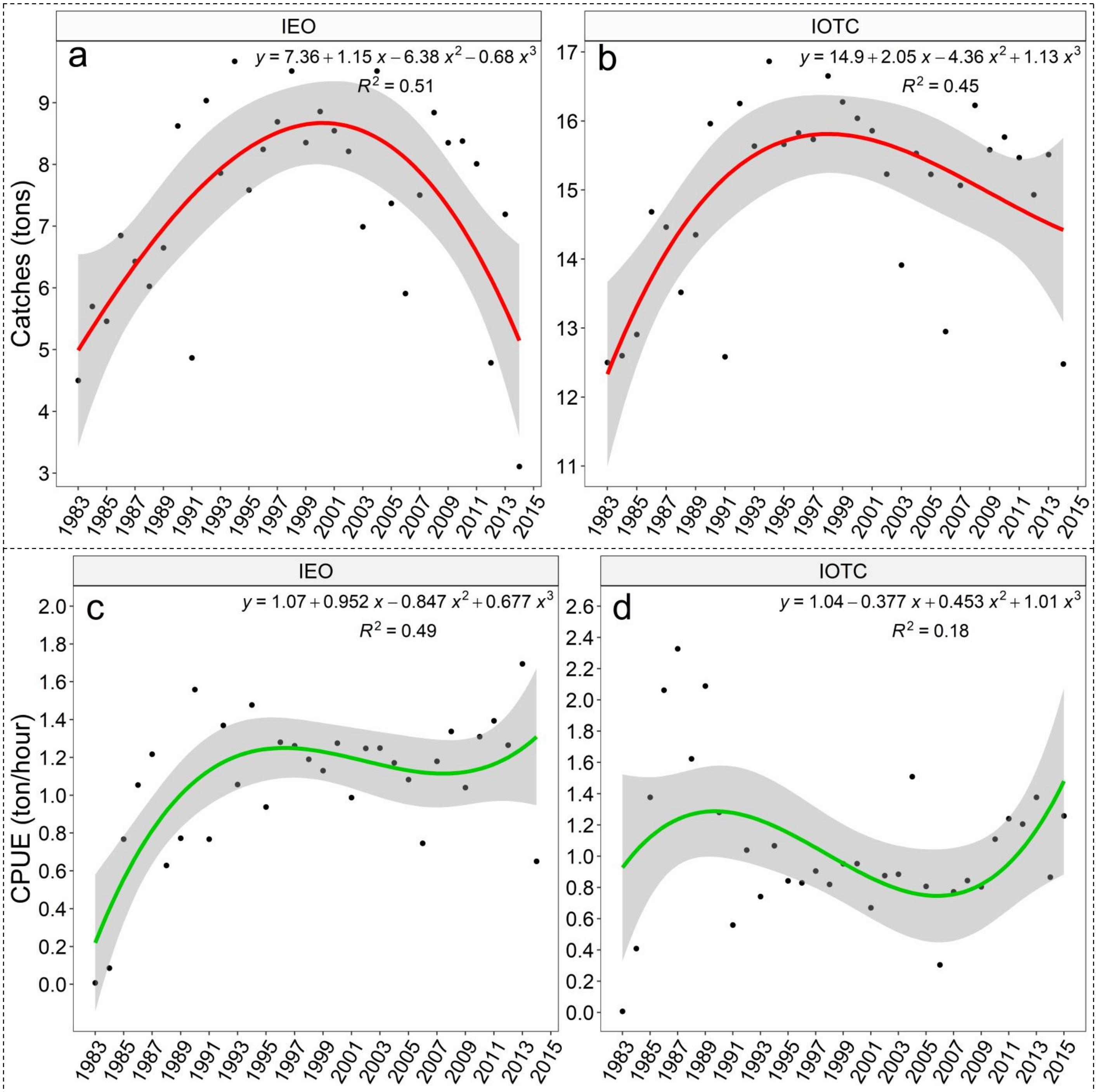

Figure 3– Catch trends (a and b) and catch per unit of effort (CPUE) (c and d) by purse seine fleets in Mozambique for the period 1983 to 2014. Catches are composed by bigeye tuna (*Thunnus obesus*), skipjack tuna (*Katsuwonus pelamis*), and yellowfin tuna (*Thunnus albacares*). Logbook data provided by the Instituto Español de Oceanografia (IEO), and commercial data provided by both the Indian Ocean Tuna Commission (IOTC). Data were transformed to a logarithmic scale to reduce the variance in order to observe trend patterns.

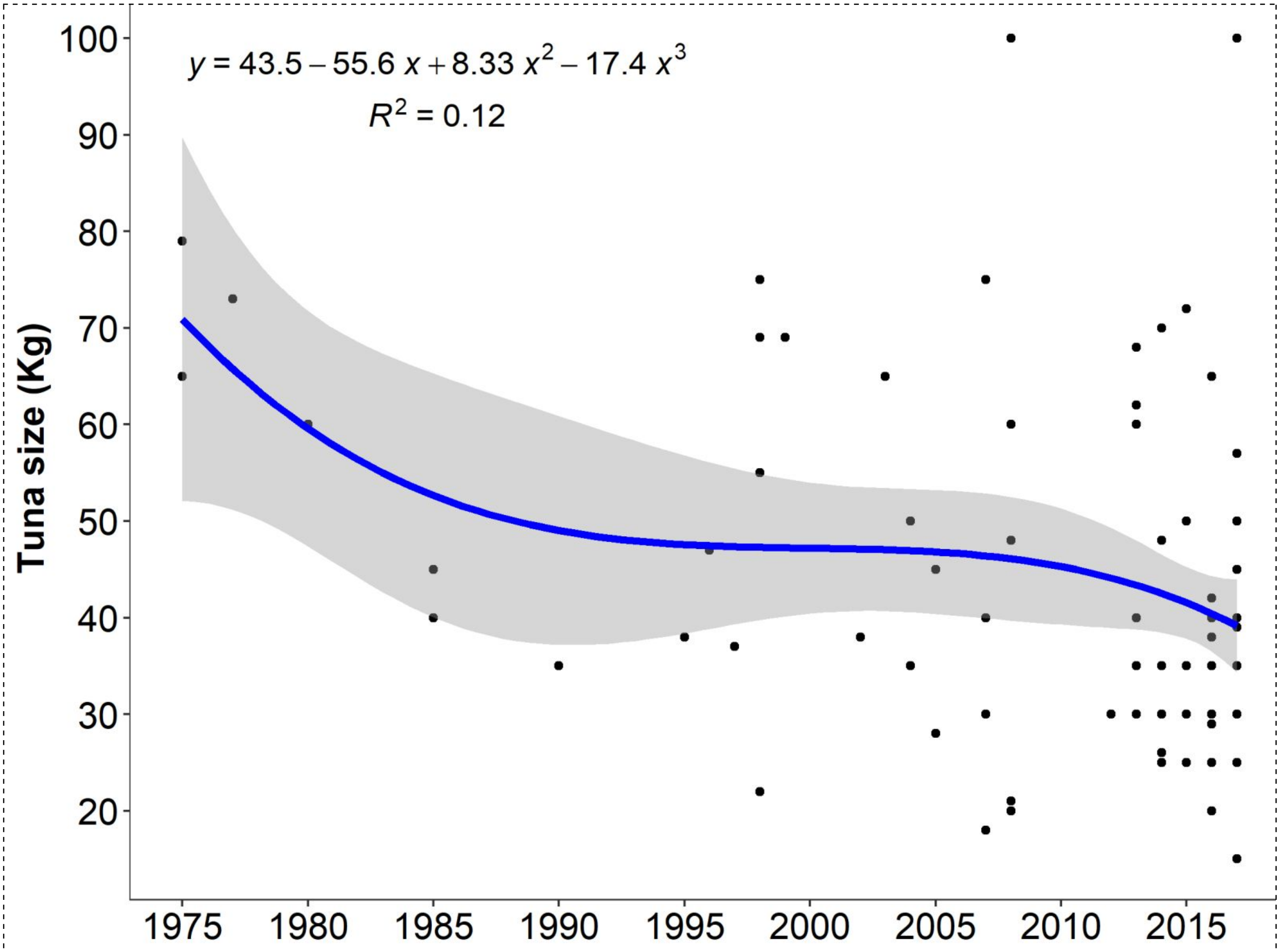

Figure 4 - Historical trend of the largest tuna ever recalled to have either been seen or caught by small-scale fishers.

Annex A- Tables

Table 1- Revenue summary for purse seine fleet under fisheries partnership agreements (FPA) between Mozambique and the European Union. Data sources: https://ec.europa.eu/fisheries and https://www.iotc.org. mt = metric tonnes. All FPAs started on 1 January and ended on 31 December

Item	**Fishing partnership agreements signed**					
Year of FPA signature	**1987[1]**			**2003**	**2007**	**2012**
Protocol agreement	**First**	**Second**	**Third**			
Duration (Years)	3	2	13	3	4	4
Number of purse seine licenses issued[2]	40	44	42	35	42±7	21±3
FPA total contribution (€/year)	2.500,000	3.430,000	280,000	600,000	650,000	980,000
Accessing fees per vessel (€ after 2003)	-	-	-	3,000	4,200	5,100
Annual fees from license (€)	40,000	44,000	42,000	105,000	176,400±29,400	107,100±15,300
Shipowner contributions per mt (€)	20	20	20	25	35	35
Reference catches per licence fee (mt)	50	50	50	120	120	146
Total allowable catches (mt)			-	8,000	10,000	8,000

[1]The number of licenses issued under 1987 FPAs included purse seine and longline vessels
[2]Number of purse seine fleet also includes other non-European vessels

Table 2 - Summary of the interview data related to changes in tuna catches, and interactions with industrial fleets. A, B and C indicate regions of clustered sampled villages. SKJ-skipjack, BET- bigeye tuna, YFT- yellowfin tuna, FAD- fishing aggregating device. Percentage values in brackets in rows of boat size correspond to the number of respondents.

Item	**Category**	**Sampling regions**			**Overall**
		A (=33)	**B (n=35)**	**C (n=33)**	**(n=101)**
Tuna species average size (kg) (% in brackets referrers to the number of fishers who reported each species per region)	SKJ	7.64 ±4.39 (76%)	4.15 ±2.19 (97%)	6.12 ±2.60 (76%)	5.77±3.41 (83%)
	BET	18.07 ±7.04 (42%)	16.19 ±4.73 (60%)	19.42 ±6.67 (56%)	17.81±6.14 (53%)
	YFT	22.82 ±8.36 (52%)	19.27 ±5.99 (42%)	16.82 ±9.51 (85%)	19.13±8.68 (60%)
Number of fishers 5 years before 2017/2018 (%)	Increased	55	63	70	62
	Did not change	33	29	6	23
	Decreased	12	8	24	15
Perceived trend of tuna abundance over the last 5-10 years before 2017 (%)	Increased	45	46	12	35
	Decreased	55	54	88	65
Has it been easy to catch tuna over the last 2 years (%)	Yes	64	37	36	54
	No	36	63	64	46
Best period of the day to catch tuna (%)	Sunrise and Sunset	85	86	85	85
	No difference	15	14	15	15
Have previously seen industrial vessels in their fishing sites (%)?	Yes	24	6	42	24
	No	76	94	58	76
Have previously seen or used FADs (%)?	No	100	100	100	100
Average Fishing Time	Hours per day	6.70±3.19	6.77±3.28	5.94±2.41	6.48±3.01
	Day per month	19±3	20±3	15±4	18±4
Boat size (m)	Engine	4-11 (33%)	8-12 (57%)	3.5-7 (79%)	3.5-12 (57%)
	Sail and rowing	2 -8.5 (67%)	3-10 (43%)	3-6 m (21%)	2.5 -11 (44%)

Table 3- Summary of the socioeconomic aspects of small-scale tuna fisheries in Mozambique. A, B and C are the sampling village regions, and *n* is the sample size. FTE- full time equivalent jobs. i, ii, and iii indicates the types of revenue sharing: boat-owner (i) - fishers are also boat owners who pay for the costs and retain all the profits; team-fishers (ii)- 50% of the income for the patron, who is also a fisher, and the remaining is divided equally among the crew; patron (iii)-60% of the revenue is shared among the crew and 40% goes for the patron, who is not part of the crew. The % presented in brackets under the variable species prices corresponds to fishers who have been catching each species in the region. Incomes and prices were converted to euros and the reference year is the sampled year 2017 (https://ec.europa.eu/budget/graphs/inforeuro.html) as follows: 1 MZN (Mozambican currency) was equivalent to €0.0140025. December - May is the high fishing season, and June - November is the low fishing season.

Item	Category	Sampled fishing villages, clustered by region		
		A (n=33)	B (n=35)	C (n=33)
	Credit	9.09	22.86	30.30
Funding sources for fishing (%)	Self-funded	75.76	54.29	60.61
	Unknown	15.15	22.86	9.09
Nº of interviewees		9	5	
Crew size - gillnets		12 ± 6	11 ± 4	
Daily working hours		11.38 ± 2.91	11.2 ± 1.47	
Fishing days		17 ± 2	19 ± 4	
FTE per month		14.20 ± 0.27	15.05 ± 0.16	
Forms of income sharing	Gillnet	ii	ii	No fisher found in
% Respondents on gillnets		24.24	14	visited villages
Boat-owner (Dec-May) €		-	793.48 ± 462.06	
Boat-owner (Jun -Nov) €		-	74.68 ± 40.15	
Fisher (Dec-May) €		371.07 ± 299.58	245.04 ± 35.01	
Fisher (Jun -Nov) €		120.77 ± 119.62	91.02 ± 21.00	
Boat size (meters)		5 - 10	4 - 7	
Nº of interviewees		14	10	33
Crew size - handline		3 ± 2	1 ± 0	5 ± 2
Daily working hours		10.36 ± 3.67	10 ± 2.61	10.88 ± 5.27
Fishing days		20 ± 3	21 ± 2	15 ± 4
FTE per month	Handline	3.89 ± 0.02	1.30 ± 0.27	5.10 ± 4.87
% Respondents on handlines		45.45	29	100
Forms of income sharing		ii and iii	ii and iii	i, ii and iii
Boat-owner (Dec-May) €		-	-	380.61 ± 239.71
Boat-owner (Jun -Nov) €		-	-	122.84 ± 79.40
Independent fisher (Dec-May) €		257.30 ± 266.50	106.57 ± 16.04	-
Independent fisher (Jun -Nov) €		87.52 ± 109.25	25.67 ± 11.43	-
Crew fisher (Dec-May) €		555.43 ± 431.79	-	346.93 ± 400.10
Crew fisher (Jun -Nov) €		303.39 ± 277.08	-	178.50 ± 244.70
Patron (Dec-May) €		-	-	644.12 ± 491.88
Patron (Jun -Nov) €		-	-	208.64 ± 117.19
Boat size (meters)		3 - 6	2.5 - 5	3 - 7
Nº of interviewee		10	20	
Crew size – purse seine		26 ± 6	23 ± 9	
Daily working hours		12 ± 4.15	11 ± 4.32	
Fishing days		18 ± 3	20 ± 3	
FTE per month		34.44 ±12.34	32.93 ±22.14	No fisher found in
% Respondents on purse seine	Small purse seine	30.30	57	visited villages for
Forms of income sharing		ii	ii	the sampling period
Boat-owner (Dec-May) €		455.08 ± 282.23	542.87 ± 325.53	
Boat-owner (Jun - Nov) €		117.27 ± 93.39	95.32 ± 82.82	
Fisher (Dec-May) €		280.08 ± 70.01	252.05 ± 224.74	
Fisher (Jun -Nov) €		80.51 ± 59.51	106.42 ± 123.22	
Boat size (meters)		8 -11	8 - 12	
Range of net income (€)	Dec-May	42.01 - 1,680.30	42.01 ± 1,400.25	42.00 ± 2,800.50
	Jun-Nov	14.00 - 840.15	14.00 ± 280.05	14.00 ± 1,050.19
	BET	1.24 ± 0.36 (42%)	1.16 ±0.33 (60%)	2.13 ± 0.59 (67%)
Species price (€)	SKJ	0.92 ± 0.29 (61%)	0.83 ±0.33 (100%)	1.84 ± 0.60 (85%)
	YFT	1.34 ± 0.40 (48%)	1.19 ± 0.32 (42%)	2.13 ± 0.43 (86%)
Tuna destination (%)	Market	100	100	49
Fisher satisfaction (%)	Satisfied	63.64	68.57	85.85
	Unsatisfied	9.09	11.43	15.15

	No comment	27.27	22.86	0

<u>Appendix S1</u>: Questionnaire applied for data collection with small-scale fishers through face-to-face interview

Data____/___/____; Place_____________________

Part -I: Bio-Data

Date of Birth/Age______________ Year Start to Fish/Fishing years: ____________

Fishing years in this village: _______ Fish years in Other Villages: _______________

Interviewee Occupation: Crew ( ) Ownership ( ) Others__________________

Did you change occupation? No ( ) Yes ( ) ; If yes when? _______________

Education level __________________________ Gender: Female ( ) Male ( )

Do you do other jobs besides fishing? ____

Part- II: Environmental Aspect

1. Do you catch or have been catching the following tuna species in this village?

Skipjack ( ) Yellowfin ( ) Bigeye ( ) Others tunas(specify)________________

1.1 Which months of high and low tuna abundance on catches?

High abundance ________________, Low abundance_____________________

1.2 What is the average size of the individual tuna do you caught usual per day/month?

Season	Yellowfin			Bigeye			Skipjack		
	Kg	Nº	Lcm	Kg	Nº	Lcm	Kg	Nº	Lcm
March-May									
Jun-Aug									
Sept-Nov									
Dec-Fev									

2. About the equipment and effort devoted to catch tuna.

2.1 What was the best effort of tuna catches in the firsts 5 years when you start to fish?

Nº of size crew_____________ Nº of trips (days) _______________

Type of gear used________________________

2.2 What is the average catch of tuna in the last 5 years? ___________________

2.3 What is the largest tuna you have been caught or seen in your life?

Size in centimetres________________ Weight in Kilos ______________

When did this happen? ________________, Where______________________

3. Can you tell us about the equipment and effort devoted to catch tuna?

4.1 What type of boat do you use to catch tuna?

Fibber with engine ( ) Wooden Sail/rowing boat ( ) Wooden boat outboard engine ( )
Canoe rowing/sail ( ) Other types (specify) ________________________

4.2 What is the boat/canoe size and size crew?

Size in meters (please specify): ______________,
Nº of permanent size crew _________, Nº of seasonal size crew___________, Other___________

4.3. What is the gear type used to catch tuna?

Local purse seine ( ) Longline ( ) Pole and line ( ) Gill net ( ) Line and hook ( )

Size of gear ____________

4.4 **How do you detect tuna schools?**
Direct observation ( ) Birds as indicators ( ) Binocular ( )
FADs ( ); specify FAD type please: ___________ Others (Specify)_______________

4.4 **How many hours do you spend working to catch tuna per season as full time (FT) or part time (PT)?**

Working hour per season	March-May		Jun-Aug		Sept-Oct		Nov- Dec	
	FT	PT	FT	PT	FT	PT	FT	PT
Travel hours to fishing ground (leave-arrive)								
Retuning hours to landing site (leave-arrive)								
Estimated fishing hours per day								
Nº of trips per week								
Estimated fishing days per month								
Estimate distance to fishing ground (Km)								
Hours of net repairing/maintenance								
Hours of boat repairing/maintenance								
Hours of selling fish								

4. **Is there any restriction type on tuna fish or bycatch species in this area?**
None ( ) Yes ( )

If yes, please tell us: restriction types_______, year started_____ Are you satisfied ( ) Not satisfied ( ) Any comments about restriction__________________________________

6. **Does the occurrence of tuna increased or declined?**
Between 2005- 2009______________________
Between 2010 -2014______________________

7. **Is tuna easier to catch in the last 2 years?**
Yes, why_______________
No, why_______________

8. **What is the best period of the day to catch tuna in this area?**

Sunrise ( ) Daytime ( ) Sunset ( ) Night-time ( ) No differences ( )

Part III- Socioeconomic Aspect and Chain Connections

9. **What are the destination of landed tuna fish?**

Feed the crew members ( ) Local middlemen ( ) restaurant ( ) retailers ( ) traders ( ) consumers ( ) others (specify)__________

10. **How did you usual sell the fish?**

Fresh fish ( ) Fresh fish on ice ( ) Frozen fish ( ) Others (specify)______________

11. How much do you sell a kilo of the following species according?

Skipjack _____________ Yellowfin______________ Bigeye_______________

12. **Do you know where the buyers come from or taking to the fish?**
National citizen ( ), citizen from neighbour country ( )
Fish are sold local ( ) fish are taken to abroad ( ) I do not know ( )

13. **Which gender usual come to buy tuna fish for business?**
Female ( ) Male ( ) Both female and male ( )
Do you know why is it so? ___________

14. **From your experience, what is the total cost for fishing?**
14.1 Daily cost or fishing trip cost
Fuel and __________ oil ______________ Ice___________
Bait_____________ , Food ___________Others _______________; Do not know ______

14.2 Annual coast
Boat license _________, fishing gear license_________, Boat maintenance _________, fishing gear maintenance___________ Do not know ____________;

;

15. **Can you tell us the cost of your fishing equipment?**
Boat /canoe____________________, size___________, type_________
Boat engine ___________________, size _______
Pole______, hook_______, line_______, Pole size_____, hook size_____, line size_____
Traditional seine______________, size___________; Do not Know__________

16. Where did you get the supply fishing equipment and materials?

17. **How do you share or divide the profits from fishing with all members?**
____
____

18. **In average how much do you earn in good and worst season of tuna abundance?**
March- May_________________, June - August __________________

September- November ____________, December - February____________

Part III- Interaction with Industrial Fishing Vessels

20. Have you ever seen industrial tuna fleets in your fishing ground?
Yes ( ) No ( ) Other type of industrial fishing vessel ( )

What type of gear do they use?___________________________

Which species are targeting? Tuna species ( ) Other species ( ) specify ______________________

There is any problem caused by industrial fleets? Yes ( ), No ( ); if yes specify the problems___
____

21 About the use of FADs by small-scale fisheries. Questions 21.2 -21.5 will proceed if the answer from 21.1 is positive (yes).

21.1 Do you use FADs? Yes ( ) No ( ) If yes; since when?________

21.2 What types of FADs do you use? Anchored FADs ( ) Drifting FADs ( ) Nº of FADs______

21.3 Is the use of FADs seasonal? Yes ( ) No ( )
If yes; please specify the season_____________________________

21.4. Do use of FADs increase or decrease your catches?
Increase the catches ( ) Decrease the catches ( ) No change in catches ( )

21.5 What is the attraction area of FADs? (1 nm≈2Km)
< 3nm_____; 3 - 5nm_______; 5-10 nm_______; >10 nm____________

22. Do drifting FADs arrive to your coast? Yes ( ) No ( )
If yes, Where?_________________

Which season? _________________

How many FADs annually?__________________

23. Did the number of FADs encountered in your area changed in the last 10 years?

Increased ( ) Decreased ( ) Number of FADs__________

Thank you for your time

Appendix S2

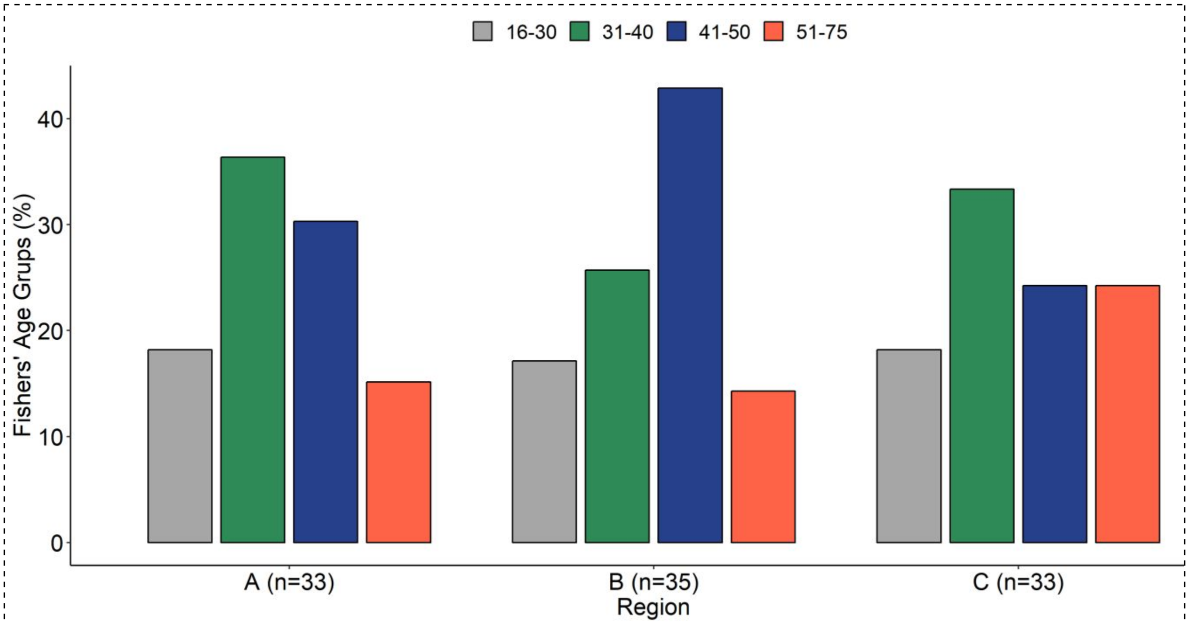

Figure S1 - Age frequency distribution for the interviewees by region. Region A and B - for the villages located in northern part of Mozambique (Cabo Delgado and Nampula provinces), C- sampled villages in southern part of the country (Inhambane and Maputo provinces). The *n* values in the brackets of regions A, B, and C correspond to the interviewed fishers in visited villages.

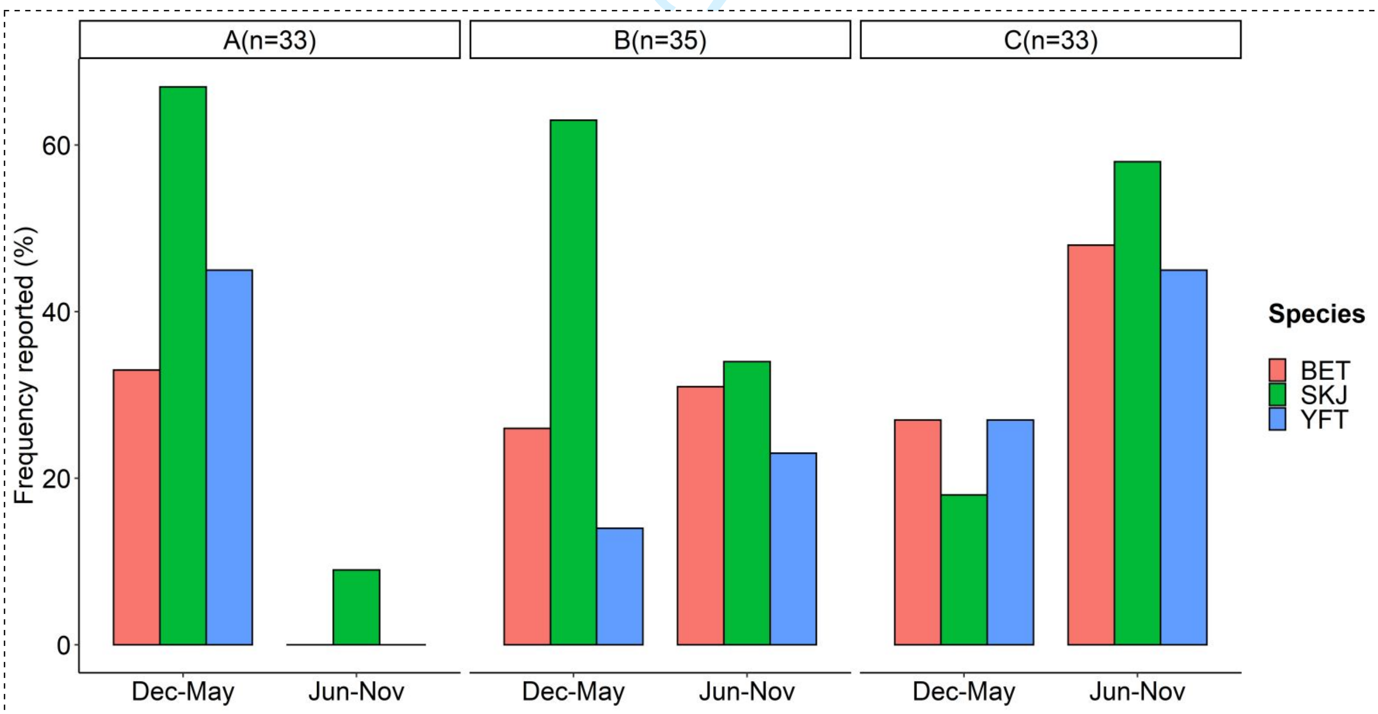

Figure S2 - Frequency of occurrence reported for each tropical tuna species for each season per region. A (northernmost, n=33 interviewed fishers), B (center-north, n=35), and C (southern, n=33) are the sampled regions. BET- Bigeye tuna, SKJ- Skipjack, and YFT-Yellowfin tuna.

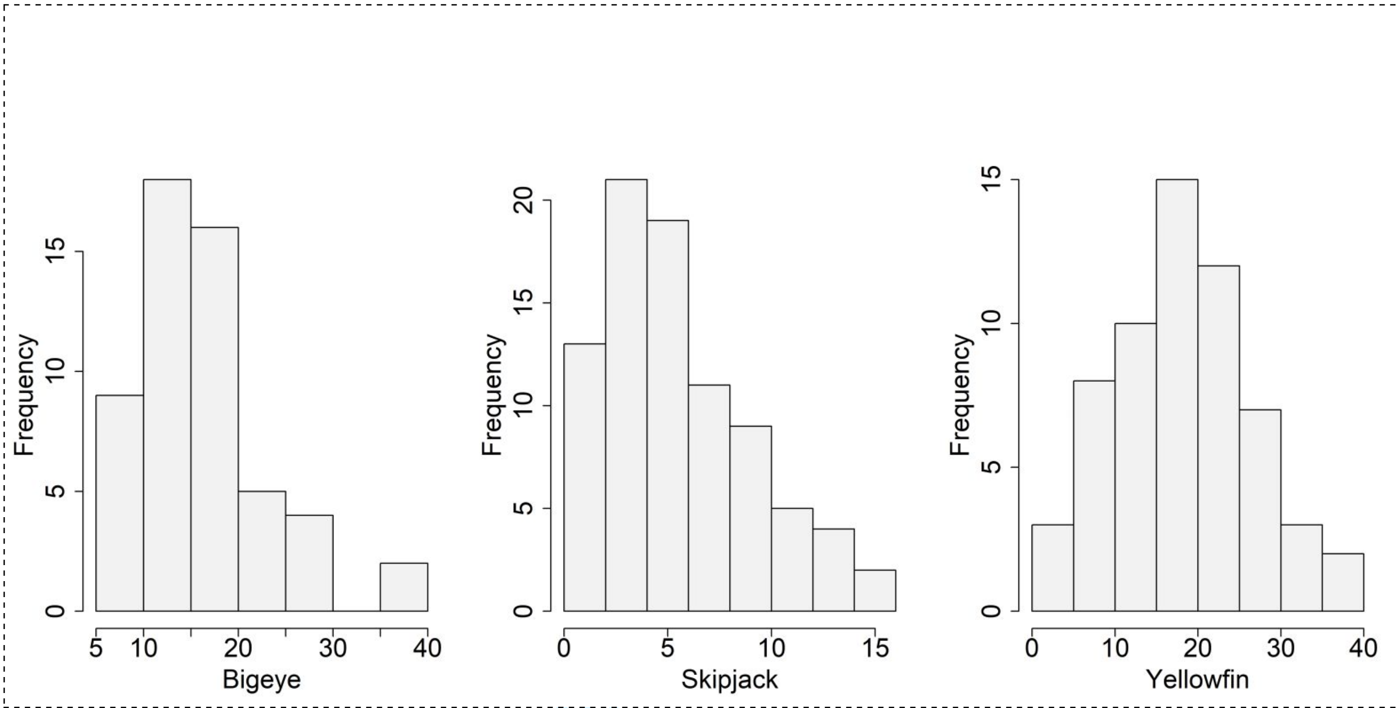

Figure S3. Frequency of average weight in kilos of regular catches for tropical tuna species reported by small-scale.

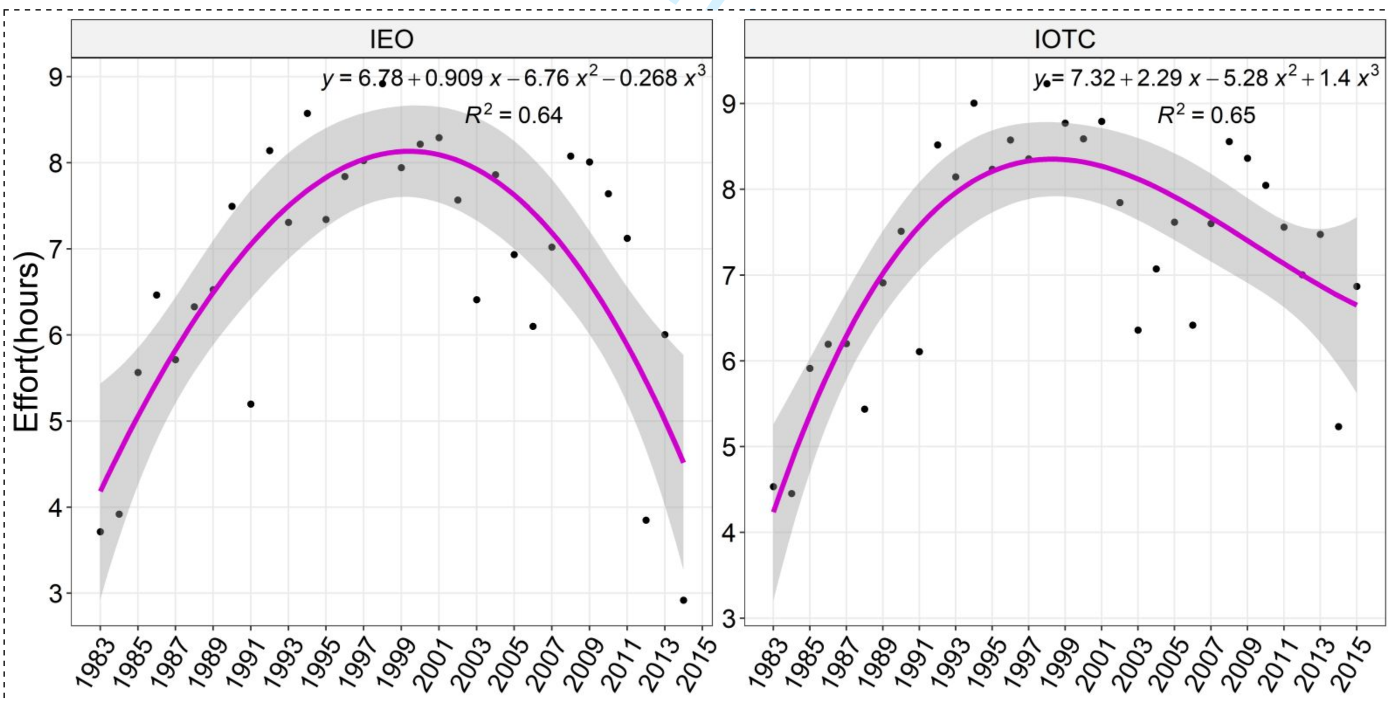

Figure S4. Evolution of fishing effort in hours transformed to the logarithm scale in Mozambique Channel for the period 1983 - 2014.